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AN INTERCOMPARISON OF CANADIAN EXTERNAL DOSIMETRY PROCESSORS FOR RADIATION PROTECTION

Prepared by

the Working Group on External Dosimetry
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Report

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INTERCOMPARISON OF CANADIAN EXTERNAL DOSIMETRY PROCESSORS FOR RADIATION PROTECTION

ABSTRACT

The five Canadian external dosimetry processors have participated in a two-stage intercomparison. The first stage involved dosimeters to known radiation fields under controlled laboratory conditions. The second stage involved exposing dosimeters to radiation fields in power reactor working environments. The results for each stage indicated the dose reported by each processor relative to an independently determined dose and relative to the others. The results of the intercomparisons confirm the original supposition: namely that the average differences in reported dose among the five processors are much less than the uncertainty limits recommended by the ICRP. This report provides a description of the experimental methods as well as a discussion of the results for each stage. The report also includes a set of recommendations.

RESUMÉ

Les cinq organismes responsables de la dosimétrie externe au Canada ont participé à une intercomparaison en deux étapes. Dans la première, des dosimètres ont été exposés à des champs de rayonnements ionisants dans un laboratoire où les conditions d'exposition étaient contrôlées. Dans la deuxième, des dosimètres ont été exposés à des champs de rayonnements ionisants près de réacteurs nucléaires. Les résultats de chaque étape indiquent la dose rapportée par l'organisme par rapport à une dose déterminée indépendamment et le rapport entre les doses rapportées. Les résultats de l'intercomparaison confirment la supposition originale, c'est-à-dire que les différences moyennes entre les doses rapportées par les cinq organismes sont de beaucoup inférieures aux marges d'erreur recommandées par la CIPR. Le présent rapport décrit les méthodes expérimentales et analyse les résultats de chaque étape. Le rapport contient également une liste de recommandations.

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LIST OF ACRONYMS

AECB - Atomic Energy Control Board
AECL - Atomic Energy of Canada Limited
ANSI - American National Standards Institute
BNGS - Bruce Nuclear Generating Station
BRMD - Bureau of Radiation and Medical Devices (of H&WC)
CDI - Canadian Dosimetry Intercomparison
CRNL - Chalk River Nuclear Laboratories
CSDA - Continuous Slowing Down Approximation
CV - Coefficient of Variation
DRD - Direct Reading Dosimeter
ECF - Element Correction Factor
F/M - Fuelling Machine
HWC - Department of National Health and Welfare
HQ - Hydro-Québec
IAEA - International Atomic Energy Agency
ICRP - International Commission on Radiological Protection
ICRU - International Commission on Radiation Units and Measurements
ISO - International Standards Organization
MCA - Multi-Channel Analyzer
NBEPC - New Brunswick Electric Power Commission
NGS - Nuclear Generating Station
NRC(C) - National Research Council of Canada
OH - Ontario Hydro
PNGS - Pickering Nuclear Generating Station
PTB - Physikalisch Technische Bundesanstalt
QA - Quality Assurance
QC - Quality Control
RCF - Run Calibration Factor
SD - Standard Deviation
TLD-100 - Harshaw TLD made of LiF with natural ratio of Li isotopes
TLD-700 - Harshaw TLD made of LiF enriched in the ^{7}Li isotope to almost 100%
TLD - Thermoluminescent Dosimetry
W/B - Whole Body

Table of Contents

Abstract ..... (i)

Résumé ..... (i)

Working Group on External Dosimetry ..... (ii)

List of Acronyms ..... (iii)

1.0 Executive Summary 1

2.0 Introduction 2

3.0 Intercomparison Methods 3

3.1 Laboratory Intercomparison 3
3.2 Field Intercomparison 10

4.0 Results and Discussion 16

4.1 Laboratory Intercomparison 16
4.2 Field Intercomparison 20

5.0 Conclusions and Recommendations 23

5.1 Laboratory Intercomparison 23
5.2 Field Intercomparison 25
5.3 General Conclusion 25
5.4 Recommendations 26

6.0 References 27

Appendices A to D - Field Intercomparison Addenda

Appendix E - A Description of Dosimetry Methods in Canada

AN INTERCOMPARISON OF CANADIAN EXTERNAL DOSIMETRY PROCESSORS FOR RADIATION PROTECTION

1.0 EXECUTIVE SUMMARY

There are five organizations which perform external beta/gamma dosimetry in Canada. Through these five external dosimetry processors, four distinct methods are used in determining whole body (deep) dose. The Working Group on External Dosimetry was formed primarily to review and compare these different methods. In order to quantify the differences in doses observed between the processors, the working group members agreed that dosimeters from each of the five organizations should be exposed to the same radiation fields. The resulting doses should then be evaluated by each respective processor by reading its own dosimeters in the normal way. This led to the two stage intercomparison which is the subject of this report. The first stage involved exposing the dosimeters to known radiation fields under controlled laboratory conditions. The second stage involved exposing the dosimeters to radiation fields in areas in power reactor working environments. The results indicated the dose reported by each processor relative to an independently determined dose and relative to the others.

In summary, the results of both the laboratory and field intercomparisons confirm the original supposition: namely that the average differences in reported dose among the five external dosimetry processors are much less than the uncertainty limits recommended by the ICRP. In view of the acceptably low discrepancies between processors, the working group does not recommend substantive changes in the individual systems as a matter of urgency.

2.0 INTRODUCTION

The Working Group on External Dosimetry was formed in April, 1982 following a proposal from the Atomic Energy Control Board (AECB). The mandate of the working group is quoted here from the minutes of the working group's first meeting, which was held in May, 1982:

> "The working group was formed primarily to discuss and hopefully resolve the issue of determining dose equivalent from external dosimeter readings ... other issues in the field of external dosimetry could also be addressed by this group. Five organizations are currently performing external beta/gamma dosimetry in Canada and these use four distinct methods of determining dose. While the results from the various methods are not significantly different when compared with the uncertainties involved in determining an individual external dose, they do cause some difficulties from a regulatory point of view and from the perspective of at least one labour organization.
>
> "The main objective of the working group is to determine a consistent approach to determining external gamma dose equivalent that could be recommended to the managements of each organization concerned and to the AECB. If this proves impossible a rationalization of the differences should be sought ...".

The theoretical aspects and rationale for each dosimetry method were discussed extensively over the course of the working group's first three meetings. At the fourth meeting, in June 1984, it was agreed that "... the quantity to be determined by external whole body dosimeters should be 'effective dose equivalent or a conservative estimate thereof'." It was further decided, at this meeting, that a two stage external dosimetry intercomparison be done amongst the five processors. One stage would be done in a controlled laboratory environment in which the energies and the radiation exposures would be known. This would permit a comparison between the processors' results and the expected results, and among the results of each system. The second stage would be done under real "in the field" conditions in the presence of mixed radiation fields. This would allow an examination of the relative responses of the different dosimeters under such circumstances, and a comparison with doses determined by an independent technique.

In the months that followed, this intercomparison was done as agreed upon:

(i) Laboratory test: Dosimeters from the five processors were simultaneously given known exposures to photon and/or beta fields of known energies under controlled laboratory conditions. The dosimeters were then sent back to their respective organizations for read-out and dose evaluation. AECL conducted these irradiations.

(ii) Field test: Dosimeters from the five processors were simultaneously exposed to radiation fields in power reactor working environments. The dosimeters were then sent back to their respective organizations for read-out and dose evaluation. Ontario Hydro conducted this stage.

Once the dose evaluations were completed, the results were analyzed and discussed at the fifth working group meeting which was held in September 1987.

This report provides the experimental methods used in the two stage intercomparison. The results of each stage are presented and discussed. This is followed by the working group's conclusions and recommendations to the AECB. A description of the personal dosimetry methods used in Canada can be found in Appendix E.

It should be noted that whole body or deep doses are considered in detail in this report. It was subsequently realized that skin dosimetry was a more complex problem requiring further analysis and discussion. It was, therefore, decided that since skin data has been collected, skin/shallow doses would be considered at future meetings and will be the subject of a future report.

3.0 INTERCOMPARISON METHODS

This section describes the methods for the laboratory and field intercomparisons.

3.1 Laboratory Intercomparison

3.1.1 Introduction

The purpose of the intercomparison was twofold:

•To enable each of five Canadian external dosimetry processors to determine the accuracy of their measurements at various photon energies and with various mixtures of beta rays, and photons.

•To permit comparisons of the results obtained when different dosimetry models, calibration techniques or dosimeters are used.

This was done by giving each dosimeter a known exposure and returning it to the processor from which it came for reading. The measured exposures and beta doses were reported to AECB by AECL and so also were the readings made by the processors.

The work performed by AECL can be explained under three headings:
- The Irradiation Protocol;
- The Exposure; and
- The Exposure Data.

3.1.2 The Irradiation Protocol

Figures 3.1 and 3.2 are diagrams of the photon and beta irradiations respectively.

For the photon irradiations, the dosimeters from the five processors were mounted on the face of a wooden block. The TLDs were coplanar with the surface of the block, and so was the axis of the cylindrical ion chamber. The positions shown in the diagram allotted to the dosimeters from each agency were used for every irradiation. The wooden block was made of ten layers of birch veneer plywood with particle wood centers, each layer being 20 mm thick. The average density of the wooden block was 657 kg m^{-3}.

The photon source was opposite the centre of the wooden block face and at least 1 metre from it. Thus, the geometrical error was, at most, 0.5% when assuming that the exposure rate was the same at the ion chamber and the dosimeters.

The ion chamber was calibrated at NRCC in 1975 April 3 (Henry 1975) and the data supplied were used for the intercomparison. A second NRC calibration done in 1985 June 10 (Shortt 1985) after the intercomparison did not reveal any significant change in calibration over the 10 year period.

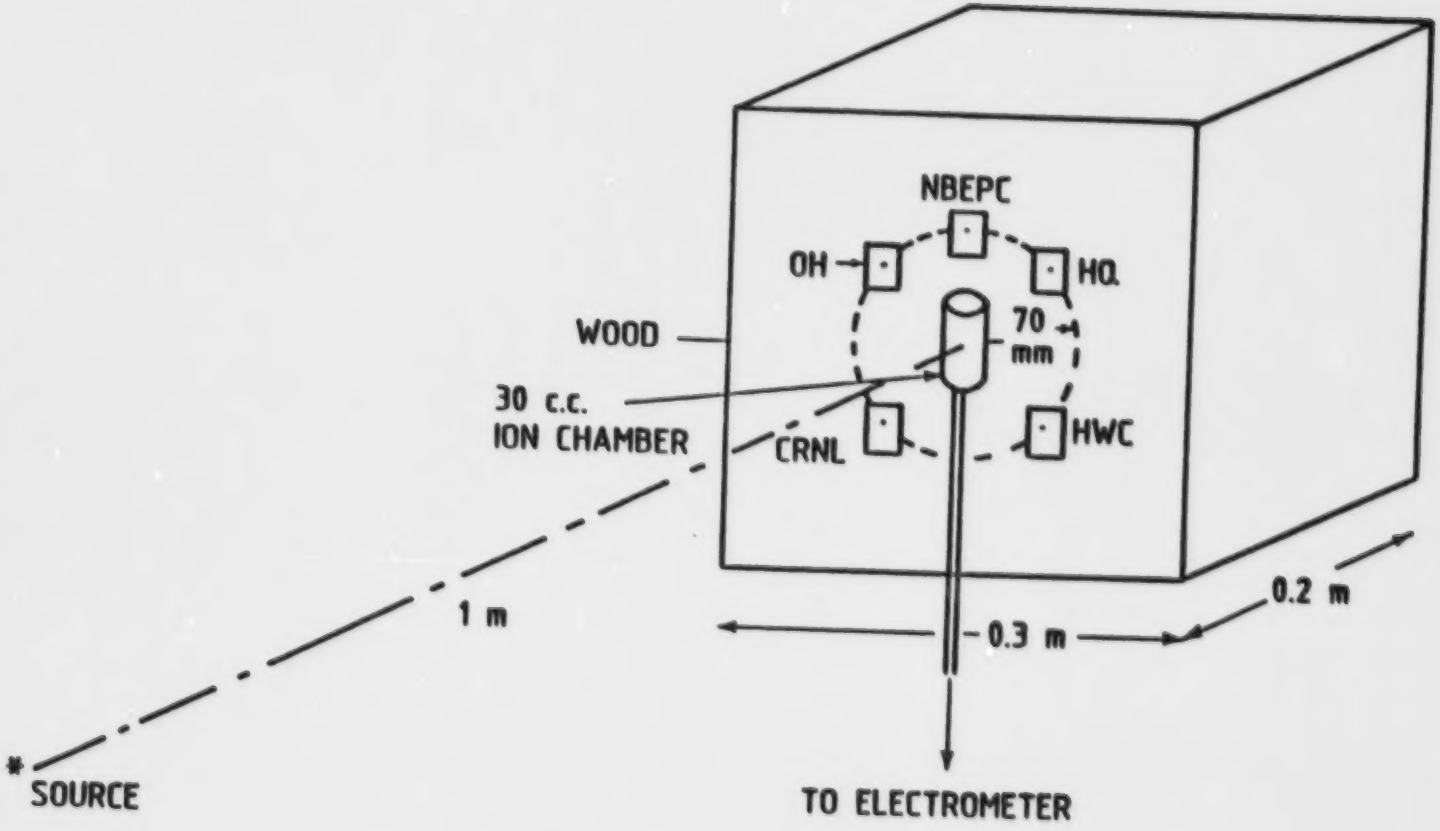

Fig. 3.1 - Photon Irradiation

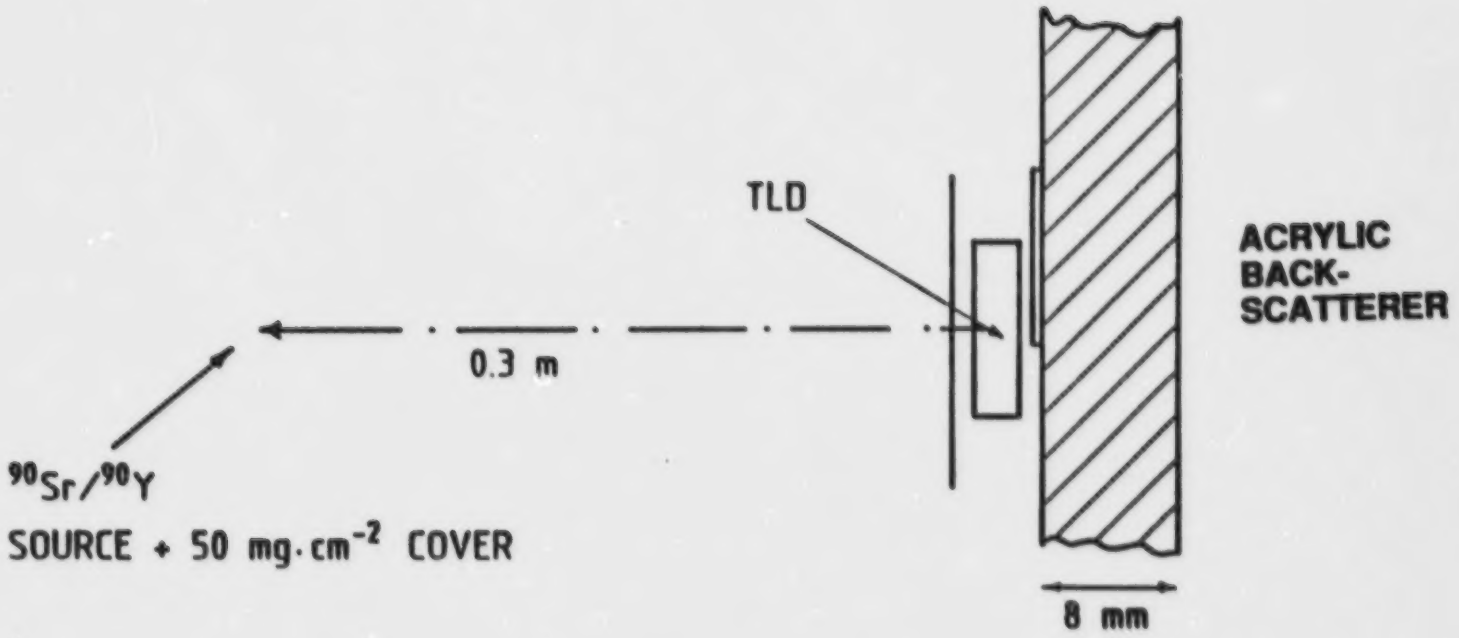

Fig. 3.2 - Beta-ray Irradiations

For the gamma ray irradiations, the ion chamber was covered by a hemi-cylindrical shell to provide electronic equilibrium.

The gamma ray sources, cobalt-60 and cesium-137, were contained in a lead shield which collimated the beam to 30 degrees.

The lower energy photon sources were obtained by filtering beams of bremsstrahlung from an X-ray set with 30-320 kV potential between anode and cathode. The filters used are specified by the ISO to produce relatively mono-energetic photons (ISO 1979).

Figure 3.2 shows the arrangement of beta-ray source and TLD, which is backed by a backscatterer. This is necessary because the dose at 70-µm depth is partly due to beta rays which are backscattered and the range of the yttrium-90 beta rays is greater than the thickness of the TLDs used.

The beta-ray source dose rate has been calibrated at PTB Braunschweig (Böhm 1981) at a distance of 0.3 metres and the dose delivered was controlled and measured with a timer.

3.1.3 The Exposure

Photons

It was decided to expose each dosimeter to about 2.6×10^{-4} C kg^{-1} (1 roentgen) to avoid the uncertainties related to small exposures which are unimportant for the purpose of this intercomparison.

Each irradiation was ended at the desired exposure. The value was read from a dosimeter (Nuclear Enterprises Ltd., model Ionex), which had been adjusted to compensate for the effects of air density and photon energy. The exposure rate was maintained at a low enough level to permit reproducible exposures.

Beta Rays

The exposure at the surface of the wooden block is not a quantity that can be measured for beta rays. Instead, the dose in tissue, at 70 µm was measured. The level chosen was 10 mGy (1 rad).

3.1.4 Exposure Data

Table 3.1 shows the levels of the exposures and tissue doses given. As a measure of the reproducibility the standard deviations follow. These last include contributions from the variability in measurement as well as variation in the delivered quantity.

TABLE 3.1

Exposures and Beta Doses Given

Photon Energy (keV)	Beta Emitter	Photon Exposure (roentgens)	Beta** Dose (rads at 70 μm)
33		1.000 ± .000	
65		1.012 ± .022	
161		1.001 ± .000	
248		1.001 ± .001	
662		1.005 ± .008	
1250		1.004 ± .001	
	Yttrium-90*		1.052
161	Yttrium-90*	0.500 ± .001	0.526
662	Yttrium-90*	0.506 ± .000	0.526

*The beta rays are described as yttrium-90 because the source covering suppresses most of the lower energy strontium-90 beta rays.

**Analysis of beta doses (70 μm depth) will be considered in a future report.

3.1.5 Uncertainties in the Given Quantities

In making comparisons between the given and evaluated quantities, it is important to estimate the uncertainties involved to judge the significance of the observed discrepancies. These are additional to any uncertainties in the models used in dose evaluation.

Exposure

Table 3.2 identifies contributors to the total uncertainty together with an estimate of the contribution expressed as a percentage.

TABLE 3.2
Uncertainty in the Given Exposure

Contributors	Contribution (%)
Precision	0-2.2
Geometrical (difference in distance from source to ion chamber or dosimeter	0.5
Variation in exposure rate over 140 mm diameter irradiation area	1.0*
Uncertainty in ion chamber calibration	1.0
Long-term drift in calibration	1.5
Tracking error from one scale to another	1.0
Errors in temperature correction	0.3
Errors in energy dependence correction	1.0*
All contributions added in quadrature	2.6-3.4

*These estimates are "educated guesses" and the consequences of errors in them can be tested.

The contributions to the uncertainty do not appear to be related so that addition in quadrature is justified.

TABLE 3.3
Uncertainty in the Given Beta Dose

Contributors	Contribution (%)
Precision of calibration	0.3
Systematic error of calibration	1.0
Geometrical error	1.3
All contributions added in quadrature	1.7

3.1.6 Effort Required

The comparison involved about 30 and 60 hours of time of a professional scientist and research technologist, respectively.

3.2 Field Intercomparison

The methods used in the dosimeter field intercomparison are summarized here. For more complete details, see Facey, 1989.

Attempts were made to characterize and classify the various beta, gamma and neutron fields encountered in this phase of the intercomparison. As anticipated, the combined fields are quite complex. They represent, however, typical situations routinely confronted in a power reactor environment. The results of these attempts to characterize the fields did not have a bearing on the outcome of the intercomparison. For this reason, they are not included in this report.

3.2.1 Phantom Design

Some fields would be of restricted size, diverging from a small source. Also, there was an overriding need for all badges in one run to "see" the same incident field. Therefore, the only practical solution was a system to rotate the badges sequentially through the same orbit in space.

The need to expose not less than three badges per run from each participant set a minimum diameter of 50 cm for a rectangular block-type phantom with a rotating front surface. There were also the constraints of cost economy and ready availability of materials.

Pressed-wood ("Medite") was chosen; similar materials (e.g., "Masonite") have long been used for building radiological phantoms (Johns 1983). The density was 0.9 g cm^{-3}. Fourteen sheets were laminated to produce the stators (non-rotating bodies of phantoms), and three sheets to make the rotors.

Phantom design and dimensions are shown in Figure 3.3. A photograph of a phantom is shown in Figure 3.4. Three phantoms were made. These weighed around 45 kg each and were assumed to be very crude representations of the human torso. The rotors were driven at 6 RPM by a motor, mounted at the rear. In Figure 3.4, the anti-contamination bagging had been partly opened, prior to demounting the badges.

3.2.2 The "Petty Phantoms"

A very important need for characterizing the various radiation fields was the measurement of a depth-dose profile in tissue. This would require a very small device, which would measure tissue dose with reasonable precision, and with a resolution of 1-3 mm along the depth axis.

This led to the design of the "petty phantom" (where the word "petty" means small or minor). Polystyrene was chosen because it has been well studied (ICRU 1972). In the present case, the plastic contained some TiO_2 (up to 4% by weight) which may improve the response to low energy photons.

The petty phantoms were made up of a stack of nine square plates of polystyrene, measuring 5 x 5 cm. The stack was approximately 3 cm deep. Each plate contained four close-fitting cavities for TLD-700 chips of LiF, 0.9 mm thick (Fig. 3.5). The device was held in a close-fitting square hole in the phantom rotor (Fig. 3.3).

At the front of the petty phantoms, 14 mg cm^{-2} of aluminized mylar tape covered the TLD chips. As the chips were 240 mg cm^{-2} thick, the chip midline for the surface chips was considered to lie at a depth of 134 mg cm^{-2} with respect to the front surface. The mean depths of all TLDs were given by the series 134, 471, 808 ..... 2830 mg cm^{-2}, in steps of 337 mg cm^{-2}.

Nine petty phantoms were made. This allowed preloading of a full set of pettys, and also allowed all TLD chips to be left in place until readout. Individual chip calibration factors were not used, but the batch showed a uniform response to within ±3% (one standard deviation).

3.2.3 Scheduling of Exposures

The experiment was planned to take place during four weeks of tests between late September and middle November 1986. Following each test week there was a week for readout, and for preparatory tasks for the test week to follow.

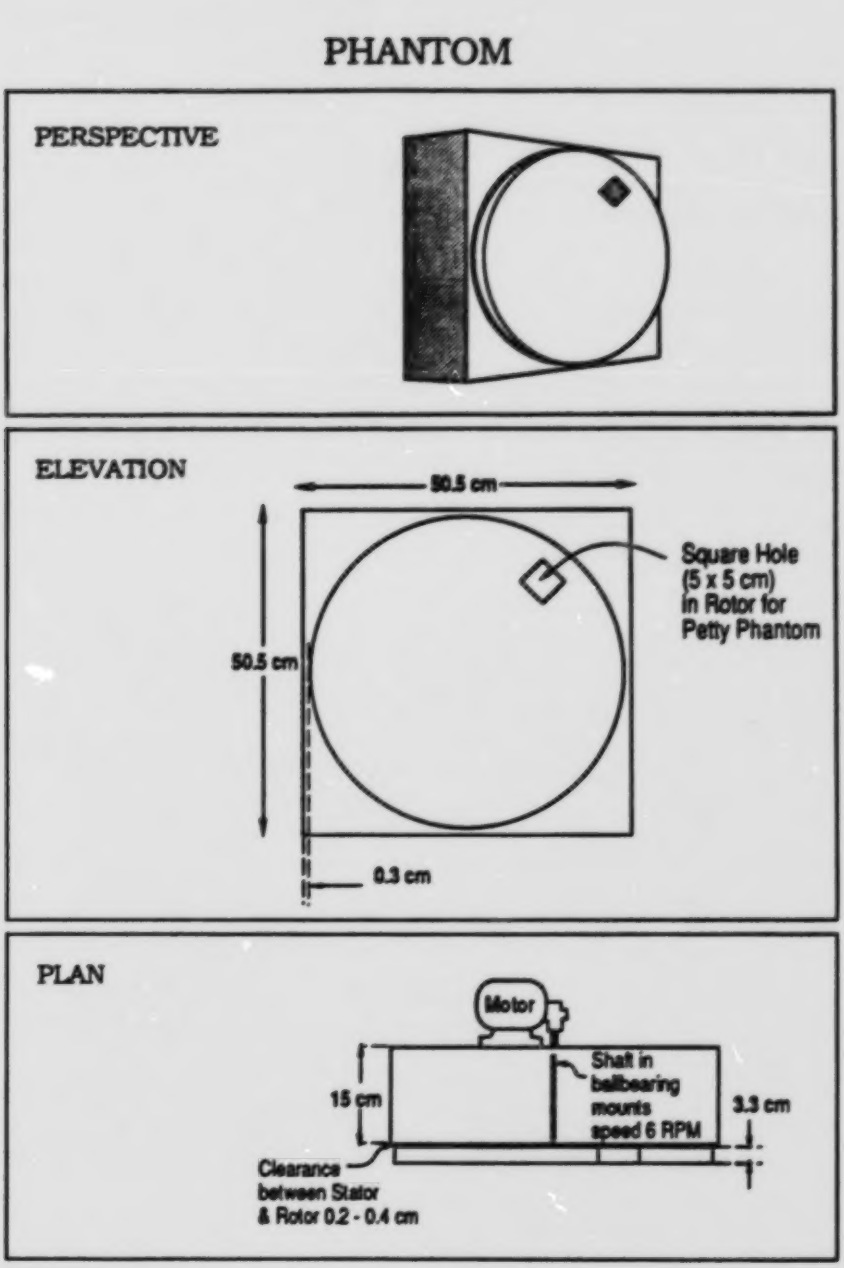

Fig. 3.3 Plan, elevation and perspective views of the large phantom. Three phantoms were made. Each held 15 TLD badges, plus one "petty phantom", pushed into close-fitting square hole in rotor.

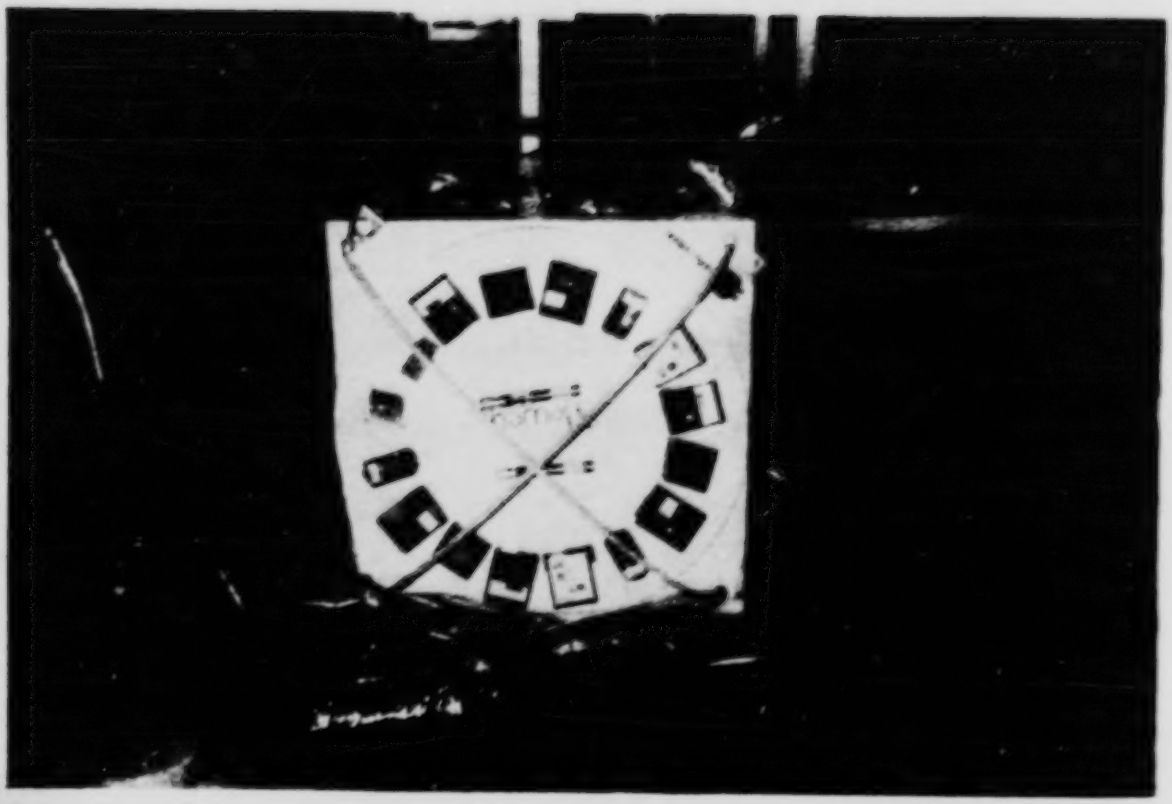

Fig. 3.4 View of phantom, with 15 badges and two DRD's (QF pocket ionization chambers) near centre. Petty phantom is located just past the "9-o'clock" position, with its front surface flush with front of rotor. The plastic bag has just been removed following an exposure at Pickering NGS.

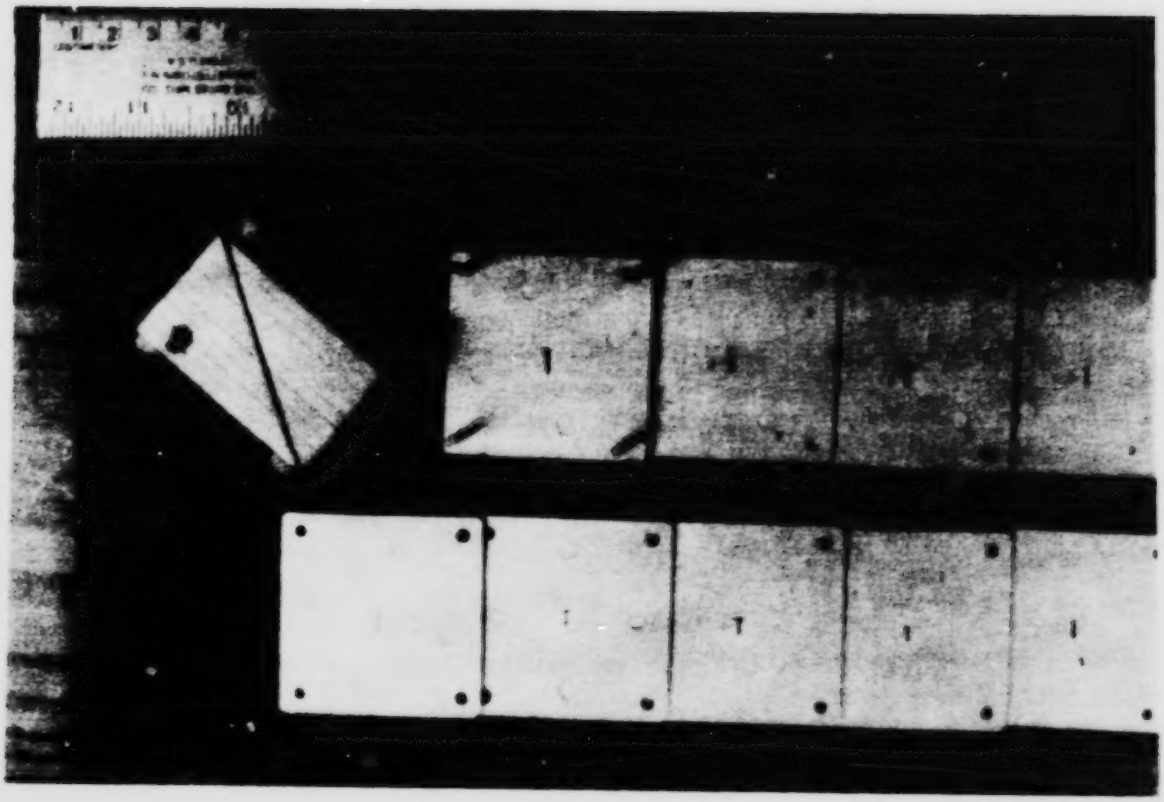

Fig. 3.5 Petty phantom is shown assembled at right, and dismantled at centre and left. Positions of cavities, for mounting four TLD chips per layer, are staggered to avoid "shadowing".

The five processors participating in the CDI were fully cooperative in the timely preparation and shipping of fresh sets of badges (four shipments per processor). In all cases the mailing date deadlines were successfully met. Through no fault of the participant, the badges from CRNL were delivered late to Ontario Hydro for Week 1, and these badges missed the first six runs.

Details on the distribution of runs and badges are given in Table 3.4. Totals on the bottom line show actual badges exposed.

TABLE 3.4

Table Showing Breakdown of the CDI Experiment

Unit	Runs	Badges per Participant	Petty Phantoms	Total Badges
1 Run	1	3	1	15
1 Week	9	27	9	135
Total CDI	36	108	36	522

3.2.4 Site Selection

For guidance the Health Physics Departments at the nuclear stations were given the list of site selection considerations shown in Table 3.5. A listing of all the sites may be found in the tables of Appendix C.

TABLE 3.5

Site Selection Considerations

1. Significant dose equivalent rates, i.e., from 50 mrem h^{-1} to 10 rem h^{-1} (0.5 mSv h^{-1} to 0.1 Sv h^{-1}), are sought.
2. Pure gamma fields are acceptable.
3. Beta fields are very important.
4. A high $\frac{\beta}{\gamma}$ ratio is desirable.
5. Reactors may be operating or shut down.
6. Neutrons are not desired, but also are not to be avoided.
7. Sites should preferably be where a substantial fraction of personnel dose is acquired.

3.2.5 Effort Required

The field intercomparison required more than 1000 hours of professional staff time and more than 1200 hours of technical staff time.

4.0 RESULTS AND DISCUSSION

This section provides the results and a discussion of the laboratory and field intercomparisons.

4.1 Laboratory Intercomparison

4.1.1 Results

As stated in the introduction, the objective of individual dosimetry is ideally the estimation of the effective dose equivalent. Since this is not practicable, a conservative estimate is acceptable if the overestimate is not too high. There are differences in the dosimeters, and in their calibration, used by the five Canadian processors and these differences should be reflected in their performances. The results of laboratory measurements, which are presented in this section, can be used to judge whether or not these differences are acceptable.

To begin, the results obtained by the processors are presented. Whatever the delivered quantities are, in an ideal world the reported results should be the same. However, there are differences between the systems used in terms of materials, treatment, calibration and dose calculation. These differences should show up as differences in the reported results which are given in Table 4.1. Data are only analyzed for the whole body (deep) dosimeters. Data for the skin (shallow) dosimeters will be discussed in a future report.

TABLE 4.1

Reported Doses (mSv) [Whole Body]

Photon Energy (keV)	Processors				
	CRNL	HQ	HWC	NBEPC	OH
33	5.14 ±13	6.62 ±13	7.58 ±29	6.51 ±17	6.54 ±22
65	7.59 ±16	9.52 ±19	11.15 ±43	7.14 ±19	9.75 ±20
161	7.57 ±14	8.88 ±27	11.07 ±24	7.98 ±25	9.00 ±30
248	7.98 ±15	8.51 ±13	10.61 ±20	8.45 ±17	8.57 ±19
662	9.03 ±19	7.70 ±20	9.75 ±30	9.79 ±24	8.48 ±19
1250	8.73 ±16	7.44 ±25	9.40 ±25	9.62 ±23	7.71 ±04

Figure 4.1 shows the ratio formed by dividing the values in Table 4.1 (the evaluated dose) by the values in Table 3.1 (the exposure).

To give an idea of the relative response of the different systems over the photon energy range, Table 4.2 shows the response of each dosimeter relative to the average of the values at each photon energy from Table 4.1.

TABLE 4.2

Reported Doses/Average Reported

Photon Energy (keV)	Processors				
	CRNL	HQ	HWC	NBEPC	OH
33	0.793	1.022	1.170	1.005	1.010
65	0.841	1.054	1.235	0.791	1.080
161	0.851	0.998	1.244	0.897	1.011
248	0.904	0.964	1.202	0.958	0.971
662	1.001	0.860	1.089	1.094	0.947
1250	1.017	0.867	1.096	1.121	0.899

4.1.2 Discussion

An important, but debatable, question is how do the evaluations compare with the "true" values. If you consider these to be the exposure at the dosimeter site, or some quantity proportional to it but independent of energy, the reported dose estimates can be compared with the given exposures (Table 3.1) which are within the range 0.99 - 1.034 R. Another basis of comparison is that between the evaluated dose and the effective dose equivalent as determined by Jones (1979). This is illustrated in Table 4.3 and is based on the effective dose equivalent for anterior-posterior irradiation to correspond with the experimental arrangement.

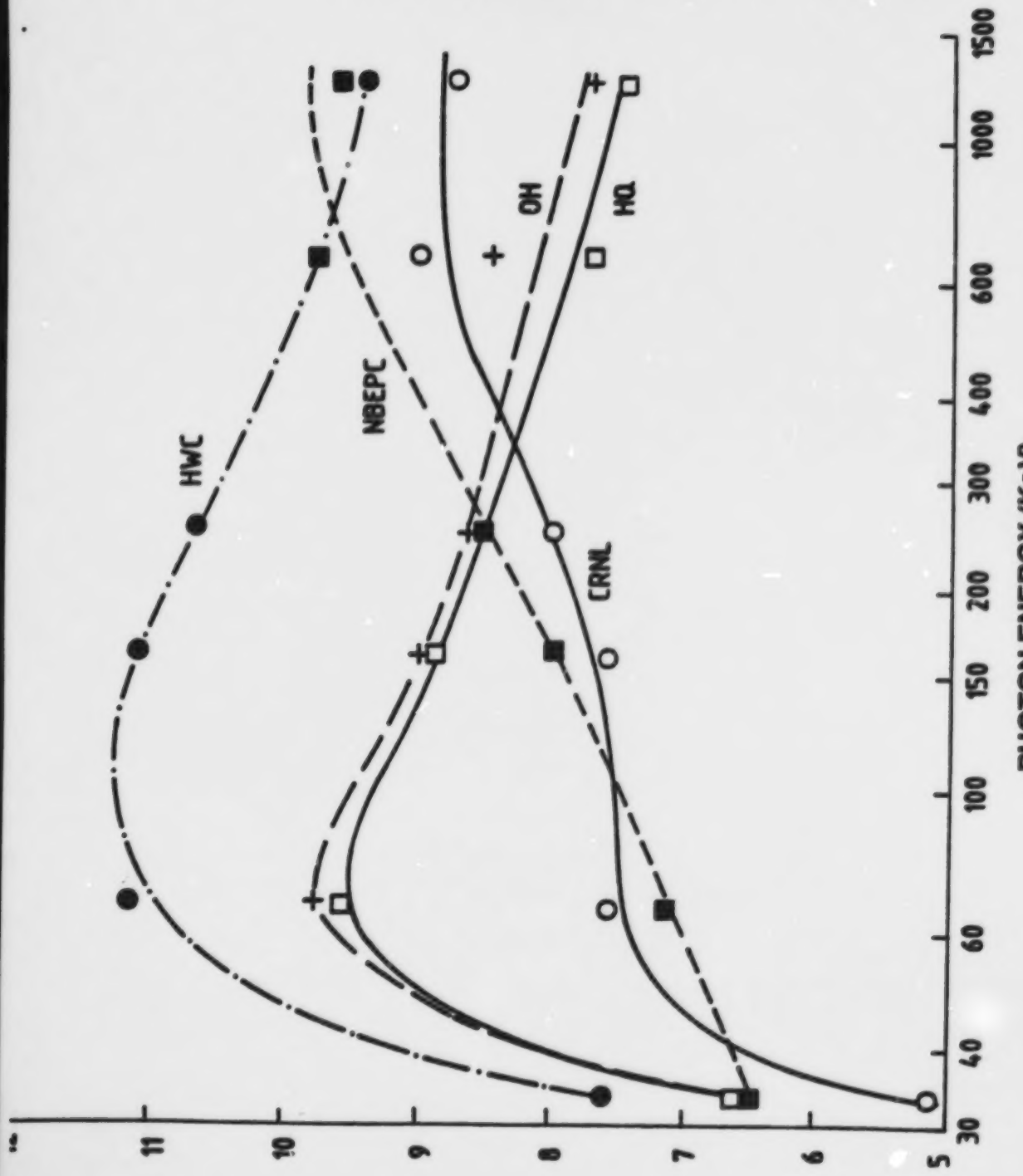

Fig. 4.1 - Photon Energy Dependence (fitted by hand)

TABLE 4.3

Evaluated Dose/Effective Dose Equivalent

Photon Energy (keV)	Processors				
	CRNL	HQ	HWC	NBEPC	OH
33	0.857	1.103	1.263	1.085	1.090
65	0.906	1.136	1.331	0.852	1.164
161	0.900	1.056	1.317	0.949	1.070
248	0.900	1.048	1.309	1.041	1.056
662	1.06	0.904	1.144	1.149	0.995
1250	1.017	0.867	1.095	1.121	0.898

Since the HQ, HWC and OH dosimeters are essentially the same, the form of the energy dependence as shown in Figure 4.1 should be approximately the same (the values may differ because of calibration differences). This is the case. The CRNL dosimeter differs because the LiF material has been sensitized which alters the photon energy dependence as well as increasing the sensitivity. This appears to be due to the fact that the sensitizing factor is reduced for high LET radiation such as neutrons and low energy photons (Jones 1980).

The NBEPC dosimeter differs in construction and materials from all the others. Therefore, the similarity in energy dependence to the CRNL dosimeter is by chance.

4.2 Field Intercomparison

4.2.1 Results

The 1986 field intercomparison was conducted as a blind test. Each processor was requested to perform a normal TLD badge readout, as for any routine badges worn by personnel. After this, the four outside participants were to mail in their results to Ontario Hydro.

4.2.1.1 Petty Phantom Readings and Normalization

As there was no "official reading", badge results were normalized to the mean of the fifteen badge readings for each run. Another method was to refer all readings to the petty phantom depth-dose data, since the badge processing and the petty phantom processing were quite independent. This provided a somewhat independent yardstick against which processors could be compared. Both methods are used in the results presented here.

4.2.1.2 Petty Phantom Depth Dose Calculations

The petty phantoms each provided 36 TLD readings, four at each of nine depths (see Section 3.2.2). The nine mean values from each run are reported in Appendix A. Also shown there is the method of calculating "Derived Depth Doses", which are estimates of petty phantom dose at depths other than those measured.

4.2.1.3 Absorbed Dose Calculation

To calculate absorbed dose in tissue, the LiF chips in the petty phantoms were treated as cavities containing LiF inside a medium of polystyrene. This required the assignment of an absorbed dose per exposure conversion factor to derive dose to soft tissue from a TLD reading calibrated in terms of exposure. The factor used was 0.965 rad R^{-1}. The derivation of this factor, and the logic of the method are given in detail in Appendix B.

4.2.1.4 Petty Phantom Results

Fully detailed results for the petty phantoms are given in Appendix A. Also shown there are the Derived Depth Doses which were calculated and used to normalize the reported badge readings.

4.2.1.5 Tabulation of Intercomparison Results

A full set of tables showing the whole body, or deep, results for all badges of all participants is given in Appendix C. The only manipulation of the data reported there was a conversion to mSv where needed.

The overall uncertainties in the results of the intercomparison are discussed in Appendix D. They are considered to lie in the range of ±10% (one standard deviation).

A complete synopsis of the 1986 CDI is presented in Table 4.4. This gives overall mean results for the five participants together with one standard deviation. The two kinds of normalization used (the "mean of each run" method, and the petty phantom method) were discussed earlier (see Sec. 4.2.1.1). The differences between the two sets of results are not significant.

Taking in each instance the worst case, the results all lie within ±27%.

TABLE 4.4

Means of Normalized Whole Body (or Deep) Dose Ratios Averaged Over All Runs

	Processors				
Normalization	CRNL	HQ	HWC	NBEPC	OH
Normalized by Mean of Run Readings*	0.927 ±0.09	1.021 ±0.06	1.208 ±0.15	0.936 ±0.16	0.896 ±0.06
Normalized by Petty Phantoms**	1.074 ±0.41	1.158 ±0.27	1.403 ±0.43	1.033 ±0.25	1.014 ±0.24

*These means are normalized for each run by the mean of the reported readings of all participants. They are calculated from 36 runs, except for CRNL, which is based on 30 runs. The uncertainties are expressed as one standard deviation.

**These means are normalized by petty phantoms derived depth doses at 1000 mg cm^{-2} using 0.965 rad R^{-1}. They are calculated from 34 runs (with 'N-1' weighting), except for CRNL, which is based on 28 runs. Petty phantom results for runs 29 and 30 are unavailable. The uncertainties are expressed as one standard deviation.

4.2.2 Discussion

Table 4.5 shows the data averaged on a week-by-week basis. These data show a distinct pattern in the results of one participant, HWC. The mean doses reported by this participant are significantly higher than average for the first two weeks, then decrease in the third week and closely approach the average by the fourth week. The fourth week's data show very good agreement, to within the range (-9%, +8%).

5.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusions drawn by the working group in view of the results of the two-stage intercomparison are contained in this section. The working group's recommendations then follow.

5.1 Laboratory Intercomparison

It has been valuable to compare the performance of the dosimeter systems, under controlled conditions. The differences noted in the laboratory results can be used to help interpret the differences observed in the field experiment. They also make it easier to understand the effect of the dose algorithms used on the doses estimated.

Despite dosimeter and calibration differences, the effective dose equivalent is estimated within the range (-15%, +34%) over the whole photon energy range and for all processors. Clearly, the range of deviations from the effective dose equivalent could be reduced by changes in calibration alone. Viewed from the perspective of a processor, the value of doing so depends upon the weight placed on the accuracy of an estimate versus conservatism. In any case, the measured discrepancies seem acceptable in the light of other sources of error in personal dosimetry (Jones 1979).

TABLE 4.5

Average Reported Dose Relative to Mean Value for Run

		Processors				
		CRNL	HWC	NBEPC	HQ	OH
Run Number	1		1.34	0.80	0.98	0.88
	2		1.27	0.83	1.05	0.85
	3		1.32	0.84	0.97	0.87
	4		1.25	0.83	1.01	0.91
	5		1.38	0.76	0.97	0.88
	6		1.27	0.87	0.96	0.90
	7	0.93	1.25	0.85	1.04	0.94
	8	0.93	1.28	0.82	1.00	0.97
	9	0.94	1.27	0.85	0.99	0.95
	10	0.96	1.30	0.99	0.96	0.79
	11	0.94	1.34	0.94	0.97	0.81
	12	0.92	1.28	1.02	0.99	0.80
	13	0.87	1.37	0.92	1.00	0.85
	14	0.84	1.36	0.95	1.00	0.86
	15	0.86	1.31	0.98	1.00	0.86
	16	0.85	1.37	0.92	1.01	0.86
	17	0.84	1.36	0.94	0.99	0.86
	18	0.85	1.40	0.87	1.02	0.86
	19	0.95	1.16	0.88	1.09	0.91
	20	0.93	1.18	0.89	1.08	0.91
	21	0.94	1.21	0.88	1.04	0.92
	22	0.75	1.46	1.09	0.90	0.79
	23	0.93	1.14	0.96	1.04	0.94
	24	1.15	0.88	0.58	1.27	1.12
	25	0.94	1.16	0.92	1.05	0.92
	26	0.92	1.16	0.90	1.09	0.93
	27	0.95	1.13	0.89	1.09	0.95
	28	1.23	1.25	0.58	1.00	0.94
	29	0.92	0.95	1.33	0.95	0.85
	30	0.93	0.93	1.25	0.99	0.90
	31	0.98	1.06	1.02	1.04	0.90
	32	0.91	1.01	1.20	1.01	0.87
	33	0.92	1.04	1.11	1.03	0.91
	34	0.92	1.01	1.07	1.06	0.94
	35	0.94	1.04	1.01	1.07	0.94
	36	0.88	0.99	1.15	1.05	0.92
All data	Mean	0.93	1.21	0.94	1.02	0.90
	S.D.	0.09	0.15	0.16	0.06	0.06
Week 1 (Runs 1-9)	Mean	0.93	1.29	0.83	1.00	0.91
	S.D.	0.01	0.04	0.03	0.03	0.04
Week 2 (Runs 10-18)	Mean	0.88	1.34	0.95	0.99	0.84
	S.D.	0.05	0.04	0.05	0.02	0.03
Week 3 (Runs 19-27)	Mean	0.94	1.17	0.89	1.07	0.93
	S.D.	0.10	0.15	0.13	0.10	0.08
Week 4 (Runs 28-36)	Mean	0.96	1.03	1.08	1.02	0.91
	S.D.	0.11	0.09	0.22	0.04	0.03

Looking back on the complete comparison, it is clear that it could have been made more useful by planning the laboratory and field experiment together. For example, if the petty phantom had been used in both parts, the dose at 1 g cm^{-2} in tissue could have been used as a common reference. Further improvements would have resulted from the use of a common major phantom and from study of angular effects in the laboratory.

5.2 Field Intercomparison

The results of the field intercomparison have been summarized in Table 4.5, where reported deep doses have been renormalized for each run to the mean value for that run. The mean values for all 36 runs show that the five processors agree to within a range of (-10%, +21%), averaged over a wide variety of exposure conditions.

In ICRP Publications 35 "General Principles of Monitoring for Radiation Protection of Workers" (ICRP 1982), it is recommended that, for doses close to the relevant annual limits, the uncertainties in external dosimetry should not exceed a factor of 1.5 at the 95% confidence level. For lower doses, a factor of 2 is acceptable. These uncertainties include "errors due to variations in the dosimeter sensitivity with incident energy and direction of incidence, as well as intrinsic errors in the dosimeter and its calibration". They do not include "uncertainties in deriving tissue or organ dose equivalents from the dosimeter results".

It is clear that, despite differences in the techniques used and in the interpretation of readings, the average differences in reported dose among the five Canadian external dosimetry processors are much less than the uncertainty limits recommended by the ICRP.

5.3 General Conclusion

A few comments are needed to explain how one selects a dosimetry model. It is a complex, and sometimes controversial, problem to transform the quantity exposure at a point in air into a dose quantity that will be a good indicator of the biological effects of irradiation. In appendix E are descriptions of the models used by the five processors. Each group essentially uses a different model. However, as we have seen from the results of this two-part intercomparison, while the reported values do differ from laboratory to laboratory, the differences are acceptable. In fact, they are valid illustrations of the differences between the dosimetry models.

What are the essential considerations that must be addressed by a dosimetry model? Energy response is the main concern. How does the relationship between dose equivalent and exposure vary with incident energy? Parameters that characterize radiation interactions with the target material (tissue) are important, and also depend on energy. At what depths in the target body does one want to estimate the dose equivalent? Considerable discussion has taken place in the last several years concerning this particular point. Are the quantities of interest determinable in a practical sense? These are among the questions that must be considered by the developer of a dosimetry model.

There is one other important consideration. Is the system practical and will it work outside the laboratory? This is probably the single most important point and the reason for which the National Dosimetry Service has chosen such a simple model, or to put it another way, why other laboratories have been able to use more complex models. In an environment where one is able to characterize adequately the radiation fields, to control workplace procedures and techniques, and to provide detailed training to facility staff, then a more complex dosimetry model can be used. Indeed, in facilities such as nuclear generating stations where large exposures may sometimes be necessary, the more detailed models are essential. On the other hand, when the scope and number of monitoring situations is large, and the radiation protection programs range from minimal to extensive, then a simpler model is warranted. As specific cases indicate the need, additional calculations can be performed and further refinement of the dose estimates developed.

5.4 Recommendations

As a result of the two-stage intercomparison, the working group recommends the following:

(i) Changes to the present dosimetry systems are not necessary to meet the recommendations of the ICRP. However, technological improvements are always encouraged.

(ii) The skin dose results form the two-stage intercomparison should be analyzed and reported separately.

(iii) Each processor should participate annually in a blind test conducted by the national standards laboratory.

(iv) At the time this intercomparison began, there was no widespread international consensus on suitable, measurable quantities for external dosimetry. In its recent Reports 39 and 43 (ICRU 1985, 1988), the ICRU has recommended the new operational quantities, individual dose equivalent penetrating and superficial. Since these quantities are gaining international acceptance, the Canadian external dosimetry processors should determine the suitability of their systems for the estimation of them.

6.0 REFERENCES

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APPENDIX A
PETTY PHANTOM RESULTS AND CALCULATIONS

A.1 Calculation of "Derived Depth Doses"

Each petty phantom readout produced 36 TLD readings, four at each of nine depths. In the tables given below, the nine mean values for each run are reported, with normalization to the deepest reading. The absorbed dose in soft tissue is also given for the deepest reading (mGy).

Also shown are the "derived depth doses" for each run. These quantities are estimates of petty phantom dose (in units of absorbed dose to soft tissue) at depths other than those actually measured.

As indicated in Table A1, derived depth dose was calculated for user badge depths for skin (or shallow) and whole body (or deep), and also at the two reference depths, 7 and 1000 mg cm^{-2}. The derived depth doses for each run are shown in Section A.2.

The method of deriving the exposure-to-dose conversion factor is given in Appendix B.

TABLE A1

Method for Calculating Derived Depth Doses from Measured Ones

DEPTHS ($mg\ cm^{-2}$) Derived→ ↓Measured	7	21	57	660	1000
134	E	E	E		
471	E	E	E	I	
808				I	I
1145					I
Application:	Reference Skin Depth	NBEPC "Shallow"	Skin Depth for OH, HQ, HWC, CRNL	W/B Depth for OH, HQ, HWC, CRNL	Reference W/B Depth, also NBEPC "Deep"

Note: "E" means extrapolation and "I" means interpolation.

A.2 Tabulation of Petty Phantom Results

The results are shown in the following tables:

PETTY PHANTOM RESULTS

(Using the factor .965 rad / roentgen)

WEEK NUMBER 1 : -

Run Number :- 2 . Petty Phantom number = 1.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 0.607 21 mg/cmsq = 0.605 57 mg/cmsq = 0.599 660 mg/cmsq = 0.529 1000 mg/cmsq = 0.524 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 0.4875 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.20, 1.09, 1.08, 1.07, 1.07, 1.01, 1.02, 1.02, 1.00

Run Number :- 1 . Petty Phantom number = 2.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 0.980 21 mg/cmsq = 0.977 57 mg/cmsq = 0.967 660 mg/cmsq = 0.835 1000 mg/cmsq = 0.824 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 0.7811 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.21, 1.10, 1.05, 1.06, 1.07, 1.04, 0.99, 0.99, 1.00

Run Number :- 3 . Petty Phantom number = 3.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 0.693 21 mg/cmsq = 0.691 57 mg/cmsq = 0.687 660 mg/cmsq = 0.629 1000 mg/cmsq = 0.611 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 0.5653 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.20, 1.13, 1.10, 1.07, 1.09, 1.03, 1.05, 1.02, 1.00

Run Number :- 5 . Petty Phantom number = 4.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 13.699 21 mg/cmsq = 13.398 57 mg/cmsq = 12.624 660 mg/cmsq = 2.960 1000 mg/cmsq = 2.235 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 1.8887 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
6.06, 2.05, 1.31, 1.18, 1.13, 1.07, 1.04, 1.02, 1.00

Run Number :- 4 . Petty Phantom number = 5.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 2.720 21 mg/cmsq = 2.709 57 mg/cmsq = 2.679 660 mg/cmsq = 2.331 1000 mg/cmsq = 2.265 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 2.1824 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.20, 1.07, 1.06, 1.02, 1.01, 1.02, 1.01, 0.99, 1.00

Run Number :- 6 . Petty Phantom number = 6.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 2.392 21 mg/cmsq = 2.379 57 mg/cmsq = 2.348 660 mg/cmsq = 2.088 1000 mg/cmsq = 2.064 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 2.0143 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.13, 0.98, 1.01, 1.04, 1.00, 1.00, 1.00, 1.01, 1.00

Run Number :- 9 . Petty Phantom number = 7.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 5.704 21 mg/cmsq = 5.697 57 mg/cmsq = 5.678 660 mg/cmsq = 5.427 1000 mg/cmsq = 5.501 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 5.3428 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.06, 1.02, 1.01, 1.04, 0.99, 1.00, 0.97, 0.97, 1.00

Run Number :- 8 . Petty Phantom number = 8.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 4.712 21 mg/cmsq = 4.699 57 mg/cmsq = 4.668 660 mg/cmsq = 4.348 1000 mg/cmsq = 4.319 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 3.8950 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.18, 1.11, 1.12, 1.10, 1.05, 1.04, 1.01, 1.02, 1.00

Run Number :- 7 . Petty Phantom number = 9.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 2.223 21 mg/cmsq = 2.222 57 mg/cmsq = 2.217 660 mg/cmsq = 2.155 1000 mg/cmsq = 2.142 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 1.9214 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.15, 1.13, 1.12, 1.11, 1.03, 1.07, 1.03, 1.01, 1.00

WEEK NUMBER 2 :-

Run Number :- 10 . Petty Phantom number = 1.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 14.557 21 mg/cmsq = 14.216 57 mg/cmsq = 13.341 660 mg/cmsq = 2.410 1000 mg/cmsq = 1.637 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 1.3565 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
8.45, 2.41, 1.28, 1.15, 1.08, 1.04, 1.03, 1.00, 1.00

Run Number :- 11 . Petty Phantom number = 2.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 9.616 21 mg/cmsq = 9.397 57 mg/cmsq = 8.833 660 mg/cmsq = 1.751 1000 mg/cmsq = 1.177 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 1.0007 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
7.62, 2.35, 1.28, 1.10, 1.07, 1.03, 1.00, 1.00, 1.00

Run Number :- 12 . Petty Phantom number = 3.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 13.831 21 mg/cmsq = 13.499 57 mg/cmsq = 12.644 660 mg/cmsq = 2.025 1000 mg/cmsq = 1.298 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 1.0574 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
10.23, 2.66, 1.33, 1.15, 1.13, 1.02, 1.03, 1.02, 1.00

Run Number :- 13 . Petty Phantom number = 4.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 13.487 21 mg/cmsq = 13.463 57 mg/cmsq = 13.403 660 mg/cmsq = 12.642 1000 mg/cmsq = 12.530 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 11.7815 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.13, 1.08, 1.07, 1.06, 1.05, 1.02, 1.03, 0.99, 1.00

Run Number :- 14 . Petty Phantom number = 5.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 7.280 21 mg/cmsq = 7.269 57 mg/cmsq = 7.238 660 mg/cmsq = 6.821 1000 mg/cmsq = 6.590 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 6.2308 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.15, 1.11, 1.09, 1.04, 1.07, 1.02, 1.01, 1.03, 1.00

Run Number :- 15 . Petty Phantom number = 6.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 7.987 21 mg/cmsq = 7.973 57 mg/cmsq = 7.937 660 mg/cmsq = 7.489 1000 mg/cmsq = 7.259 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 6.6290 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.19, 1.14, 1.10, 1.09, 1.13, 1.09, 1.07, 1.05, 1.00

Run Number :- 16 . Petty Phantom number = 7.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 6.406 21 mg/cmsq = 6.399 57 mg/cmsq = 6.380 660 mg/cmsq = 5.977 1000 mg/cmsq = 5.880 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 5.3353 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.19, 1.16, 1.09, 1.11, 1.05, 1.04, 1.03, 0.99, 1.00

Run Number :- 17 . Petty Phantom number = 8.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 6.225 21 mg/cmsq = 6.218 57 mg/cmsq = 6.200 660 mg/cmsq = 5.756 1000 mg/cmsq = 5.595 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 4.9065 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.26, 1.22, 1.14, 1.14, 1.09, 1.06, 1.06, 1.03, 1.00

Run Number :- 18 . Petty Phantom number = 9.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 3.360 21 mg/cmsq = 3.358 57 mg/cmsq = 3.354 660 mg/cmsq = 3.222 1000 mg/cmsq = 3.114 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 2.8582 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.17, 1.16, 1.10, 1.08, 1.05, 1.04, 1.04, 1.01, 1.00

WEEK NUMBER 3 :-

Run Number :- 19 . Petty Phantom number = 1.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 5.903 21 mg/cmsq = 5.887 57 mg/cmsq = 5.845 660 mg/cmsq = 5.358 1000 mg/cmsq = 5.328 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 4.8449 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.19, 1.11, 1.11, 1.09, 1.04, 1.02, 0.99, 1.03, 1.00

Run Number :- 20 . Petty Phantom number = 2.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 3.539 21 mg/cmsq = 3.535 57 mg/cmsq = 3.522 660 mg/cmsq = 3.373 1000 mg/cmsq = 3.307 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 2.9396 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.19, 1.15, 1.15, 1.11, 1.08, 1.08, 1.04, 1.02, 1.00

Run Number :- 21 . Petty Phantom number = 3.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 16.870 21 mg/cmsq = 16.834 57 mg/cmsq = 16.740 660 mg/cmsq = 15.414 1000 mg/cmsq = 14.966 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 12.8739 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.28, 1.22, 1.18, 1.15, 1.13, 1.10, 1.05, 1.04, 1.00

Run Number :- 22 . Petty Phantom number = 4.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 7.113 21 mg/cmsq = 7.094 57 mg/cmsq = 7.045 660 mg/cmsq = 6.445 1000 mg/cmsq = 6.400 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 5.7287 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.21, 1.13, 1.12, 1.12, 1.09, 1.04, 1.05, 1.02, 1.00

Run Number :- 24 . Petty Phantom number = 5.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 10.812 21 mg/cmsq = 10.777 57 mg/cmsq = 10.686 660 mg/cmsq = 9.532 1000 mg/cmsq = 9.433 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 8.1552 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.29, 1.18, 1.16, 1.16, 1.12, 1.09, 1.05, 1.05, 1.00

Run Number :- 23 . Petty Phantom number = 6.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 16.858 21 mg/cmsq = 16.787 57 mg/cmsq = 16.602 660 mg/cmsq = 14.306 1000 mg/cmsq = 14.133 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 12.0712 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.34, 1.20, 1.17, 1.17, 1.14, 1.10, 1.07, 1.05, 1.00

Run Number :- 25 . Petty Phantom number = 7.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 10.080 21 mg/cmsq = 10.064 57 mg/cmsq = 10.023 660 mg/cmsq = 9.450 1000 mg/cmsq = 9.297 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 8.2720 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.20, 1.15, 1.13, 1.12, 1.10, 1.05, 1.03, 1.02, 1.00

Run Number :- 27 . Petty Phantom number = 8.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 7.575 21 mg/cmsq = 7.580 57 mg/cmsq = 7.592 660 mg/cmsq = 7.668 1000 mg/cmsq = 7.579 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 6.8871 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.11, 1.12, 1.11, 1.10, 1.08, 1.04, 1.02, 1.07, 1.00

Run Number :- 26 . Petty Phantom number = 9.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 6.261 21 mg/cmsq = 6.255 57 mg/cmsq = 6.238 660 mg/cmsq = 5.937 1000 mg/cmsq = 5.724 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 5.3513 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.16, 1.13, 1.09, 1.05, 1.05, 1.04, 1.03, 0.98, 1.00

WEEK NUMBER 4 :-

Run Number :- 28 . Petty Phantom number = 1.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 32.595 21 mg/cmsq = 31.814 57 mg/cmsq = 29.805 660 mg/cmsq = 4.052 1000 mg/cmsq = 1.517 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 1.0181 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
25.05, 6.58, 1.94, 1.15, 1.10, 1.04, 1.02, 1.01, 1.00

Run Number :- 29 . Petty Phantom number = 2.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 6.173 21 mg/cmsq = 6.094 57 mg/cmsq = 5.892 660 mg/cmsq = 3.452 1000 mg/cmsq = 3.239 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 2.7737 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.97, 1.29, 1.21, 1.13, 1.17, 1.08, 1.05, 1.04, 1.00

Run Number :- 30 . Petty Phantom number = 3.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 3.499 21 mg/cmsq = 3.452 57 mg/cmsq = 3.331 660 mg/cmsq = 1.827 1000 mg/cmsq = 1.695 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 1.3895 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
2.21, 1.40, 1.25, 1.20, 1.16, 1.14, 1.08, 1.01, 1.00

Run Number :- 31 . Petty Phantom number = 4.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 4.613 21 mg/cmsq = 4.597 57 mg/cmsq = 4.558 660 mg/cmsq = 3.996 1000 mg/cmsq = 3.054 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 3.4432 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.30, 1.19, 1.13, 1.11, 1.09, 1.04, 1.02, 1.03, 1.00

Run Number :- 33 . Petty Phantom number = 5.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 5.073 21 mg/cmsq = 5.054 57 mg/cmsq = 5.006 660 mg/cmsq = 4.319 1000 mg/cmsq = 4.151 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 3.6250 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.35, 1.23, 1.16, 1.13, 1.09, 1.08, 1.06, 1.02, 1.00

Run Number :- 32 . Petty Phantom number = 6.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 4.934 21 mg/cmsq = 4.915 57 mg/cmsq = 4.866 660 mg/cmsq = 4.217 1000 mg/cmsq = 3.945 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 3.6111 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.32, 1.19, 1.15, 1.05, 1.06, 1.03, 1.02, 1.01, 1.00

Run Number :- 34 . Petty Phantom number = 7.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 9.561 21 mg/cmsq = 9.550 57 mg/cmsq = 9.520 660 mg/cmsq = 9.162 1000 mg/cmsq = 9.073 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 7.9173 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.19, 1.16, 1.16, 1.14, 1.07, 1.05, 1.04, 1.03, 1.00

Run Number :- 36 . Petty Phantom number = 8.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 6.945 21 mg/cmsq = 6.954 57 mg/cmsq = 6.976 660 mg/cmsq = 7.041 1000 mg/cmsq = 6.859 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 6.3419 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.11, 1.14, 1.09, 1.08, 1.06, 1.07, 1.06, 1.03, 1.00

Run Number :- 35 . Petty Phantom number = 9.

Derived Depth Doses (extrapolated or interpolated), calculated at 5 depths :-
7 mg/cmsq = 15.411 21 mg/cmsq = 15.397 57 mg/cmsq = 15.364 660 mg/cmsq = 14.082 1000 mg/cmsq = 14.187 mSv

Mean dose measured at the Petty Phantom deepest level (2830 mg/cmsq) = 12.5999 mSv

Means for each PP level, normalized to deepest level (2830 mg/cmsq) :-
1.21, 1.19, 1.16, 1.10, 1.11, 1.08, 1.07, 1.04, 1.00

APPENDIX B

DERIVATION OF THE EXPOSURE TO DOSE CONVERSION FACTOR

B.1 Method for LiF Chips in Petty Phantoms

Since the CDI work is reported in units of dose equivalent (mSv), the petty phantom results must also be reported in the same units. The TLD measurements inside the petty phantoms were made with LiF chips (TLD-700, 3.2 x 3.2 x 0.9 mm). The chip readout was calibrated in terms of exposure, measured by an ion chamber traceable to NRC, Canada, using a Cs-137 source. The raw TLD results were therefore in units of exposure, or "equivalent exposure".

The chips were placed in shallow recesses in each polystyrene slice. The depths of the recesses corresponded closely to the chip thickness. Thus, despite small air pockets at the side edges of the chips, the cavities could be described as "close fitting" in the normal direction, perpendicular to the surface.

To obtain suitable units a factor is required which will provide conversion from exposure to absorbed dose. This leads directly to dose equivalent, since the quality factor is unity for both gamma rays and beta rays.

B.2 Method for Deriving the Conversion Factor

Since the chips could be considered to be LiF-filled cavities in an extended polystyrene medium, the use of cavity theory was indicated. The cavity thickness (240 mg cm^{-2}) was of the same order as the ranges of some of the secondary electrons generated by the phantom exposures (e.g. 550-keV electrons). Thus the cavities could not correctly be considered to be either "thin" or "thick", but intermediate in size.

A situation of intermediate cavity thickness is best handled by the Burlin method (Burlin 1966, 1968). This involves the calculation of a dose partition factor, d. The factor d represents that fraction of the absorbed dose in the cavity which is carried in by the electron flux from the surrounding medium. In a very thin cavity, d would be very close to 1, and virtually all dose would be delivered by this mechanism. The remaining fraction, (1-d), is dose directly deposited by photon interactions in the cavity medium itself. In a very

large cavity, virtually all the cavity dose would be delivered this way, and d would be close to zero.

If d can be calculated, then the ratio of the dose in the cavity (LiF) to the dose in the medium (polystyrene) is given by the sum of contributions from the two mechanisms. Equation (1), taken from Attix (1986, p. 249), expresses this partitioning method.

$$R_D = \frac{D_{LiF}}{D_{poly}} = d \cdot {}_mS_p^L + (1-d) \cdot \left(\frac{\mu_{en}}{\rho}\right)_p^L \qquad (1),$$

Where ${}_mS_p^L$ is the mean ratio of mass stopping power for electrons in LiF and polystyrene, and $\left(\frac{\mu_{en}}{\rho}\right)_p^L$ is the mean ratio of mass absorption coefficients in the same two media.

The dose partition factor, d, may be calculated from β, the "apparent" or "effective" mass attenuation coefficient, if one makes the assumption that the electron spectrum entering the cavity is not significantly changed in shape, but merely exponentially absorbed by the cavity material at all energies equally. The theory recognizes that exponential absorption of an electron flux (unlike a photon flux) is only approximately true, within certain limits. Equation (2) shows the derivation of d :-

$$d = \frac{1 - e^{-\beta L}}{\beta L} \qquad (2),$$

where L is the "chord length" for the cavity, in units of mass thickness, calculated from the cavity dimensions. Equation (3) relates L to cavity size :-

$$L = \frac{4 \rho V}{A} \qquad (3),$$

where V and A are, respectively, the cavity volume and surface area, and ρ is the density of the cavity medium, which for Harshaw LiF chips is taken to be 2.63 g cm^{-3}.

The quantity β is a function of electron energy. It is calculated by an equation of Janssens (1974), modified from Burlin (1969), given as Eq. (4).

$$e^{-\beta t_{max}} = 0.04 \qquad (4),$$

where t_{max} is taken as the depth (mass thickness) to which only 4% of the electrons can penetrate.

B.3 Calculation of β

The value of t_{max} in Eq. (4) is given by the product of the CSDA range, R_{CSDA}, and a factor that depends on Z and on electron energy. The range may be obtained from tables in Attix (1986, p. 585). For low-Z materials, the factor is 0.95 at all energies (Attix 1986, p. 185). Rearranging Eq. (4) and inserting these quantities gives :

$$\beta = \frac{-\ln(0.04)}{t_{max}} = \frac{3.2189}{0.95 R_{CSDA}} = \frac{3.3883}{R_{CSDA}} \qquad (5).$$

A listing of values of the "attenuation coefficient", β , calculated from Eq. (5) is shown in Table B.1.

TABLE B.1

Listing of calculated values of the "attenuation coefficient", β , for electrons.

Electron Energy (keV)	β ($cm^2\ g^{-1}$)	Electron Energy (keV)	β ($cm^2\ g^{-1}$)
10	10652	500	15.52
15	5229	550	13.61
20	3149	662	10.60
30	1542	800	8.29
40	930	1000	6.27
50	629	1250	4.79
60	458	1500	3.87
80	279	2000	2.80
100	191	3000	1.81
150	97	4000	1.35
200	61	5000	1.08
300	33	6000	.90
400	21	8000	.68
		10000	.55

B.4 Calculation of the Dose Partition Factor, d

In principle, the derivation of the dose partition factor, d, is quite simple. At each electron energy, one can use Eq. (2) after inserting the appropriate value of β.

There are problems in practice, which make this approach difficult. The principal problem has to do with the uncertainty in the electron spectrum in and around the cavity. Since each mono-energetic gamma ray gives rise to a full secondary electron spectrum, an integration with respect to electron energy is called for. However, most of the CDI gamma spectra show a multiplicity of gamma ray peaks, as well as a very extensive distribution of Compton photons in many cases, so that a second integration with respect to photon energy is also needed.

A further complication is that three or four different mechanisms are usually contributing to the electron flux. These are the photoelectric and Compton effects, and pair and triplet production. It is true that these produce known or calculable electron distributions, but they add to the general complexity and slowness of this approach.

B.5 The Problem of Mean Electron Energy

The difficulties in applying Eqs. (2) and (5) may be summed up by noting that our knowledge of the local radiation environment is restricted to the line energies of a collection of gamma ray photons, or to the distribution shape of a Compton photon continuum. This assumes in both cases that the gamma spectra, as acquired, can be successfully de-convoluted mathematically. The problem is compounded by the fact that the proposed equation is set up to provide partition factors for an initially mono-energetic electron field.

There appear to be only two approaches at this point. In the first approach the electron energy distribution spectrum has to be calculated, and used with the double integration method discussed in the last section. This is difficult, time consuming, and possibly inaccurate.

The second, and potentially simpler method would be to calculate, or otherwise assign a "mean electron energy", or an "effective electron energy" in each situation or run. This is in a sense a "hindsight" approach, since the "effective electron

energy" would be that energy which, when applied to Eqs. (2) and (5), as if all electrons were at this one energy, would yield the correct value of d. This appeared at first to be a worthless approach, since we have no criteria to judge when d reaches a correct value.

B.6 Sensitivity of Results to Changes in d

Equation (1) is the sum of two terms; the first term contains a ratio of stopping powers for two low Z materials, and the second term contains a ratio of mass energy absorption coefficients for the same two materials. The relative importance of each term in the final answer is set by the two partition factors, d and (1-d). The sum of both terms will therefore be less sensitive than either term alone to variations in factor d.

A further consideration is that both ratios do not change rapidly with energy over a restricted energy range. Also, because of closeness of the two materials in effective atomic number, the unweighted ratios will not differ very greatly from unity. Both of these effects will make the sum less sensitive to changes in d.

The final sum of the partition equation will lead to the required R_D. The sensitivity of R_D to changes in d was tested by introducing a parameter, P, which is defined in Eq. (6). The whole method rests on the assumption that a "mean effective electron energy" does exist for these purposes. The parameter P then expresses that electron energy as a fraction of the incident photon energy:

$$P = \frac{\text{Mean effective electron energy}}{\text{Incident gamma energy}} \qquad (6).$$

Sensitivity testing was carried out by assigning a series of values to P and then calculating β and d as before. Assigned values of P lay in the range between 1.0 and 0.05. An upper limit of 0.5 would have been adequate since the Compton effect tends to dominate, and mean energy of Compton electrons over incident photon energy will not significantly exceed 0.5. The lower limit was set because CSDA tables are not available for electrons below 10 keV in energy.

Several calculations were then made and compared. An example of one such calculation is shown in Tables B.2 and B.3.

To simplify the evaluation of these calculations, it was important to condense the whole operation down into a single number, or a small set of numbers. This was done by averaging the R_D's. Each R_D was weighted by the logarithmic energy interval (midpoint to

TABLE B.2

Data for Calculating Dose Ratios (Cavity / Medium) for LiF Chips Embedded in polystyrene.

Based on the dose partition method of Burlin (1966).
β is based on Janssens (1974) and Burlin (1969) (as quoted in Attix 1986, page 251).

d is taken from a file where the energy ratio (electron / photon) is given by the parameter P. For this run P = 0.2

Electron Energy (keV)	Partition Factor d	$m s_p^L$	$\left(\frac{\mu_{en}}{\rho}\right)_p^L$
10	0	.7929	3.2726
15	0	.8007	3.4201
20	0	.8036	3.4511
30	0	.7611	3.1704
40	0	.6448	2.5342
50	.0005	.5407	1.9027
60	.0007	.4958	1.4904
80	.0011	.5477	1.1033
100	.0016	.6522	.9737
150	.0032	.7737	.8859
200	.0054	.8041	.8706
300	.0109	.8180	.8608
400	.0179	.8206	.8612
500	.0262	.8237	.8621
550	.0313	.8238	.8616
662	.0426	.8265	.8612
800	.0576	.8257	.8585
1000	.0820	.8278	.8600
1250	.1178	.8306	.8606
1500	.1534	.8283	.8613
2000	.2315	.8249	.8611
3000	.3769	.8317	.8636
4000	.4881	.8316	.8737
5000	.5700	.8290	.8846
6000	.6308	.8325	.8941
8000	.7132	.8316	.9091
10000	.7657	.8316	.9310

TABLE B.3

Results from the Partition Equation

Electron Energy (keV)	$d._m S_p^L$	$(1-d)\left(\frac{\mu_{en}}{\rho}\right)_p^L$	R_D
10	0	3.2726	3.2726
15	0	3.4201	3.4201
20	0	3.4511	3.4511
30	0	3.1704	3.1704
40	0	2.5342	2.5342
50	.0003	1.9017	1.9020
60	.0003	1.4894	1.4897
80	.0006	1.1021	1.1027
100	.0011	.9721	.9732
150	.0025	.8831	.8855
200	.0043	.8659	.8702
300	.0089	.8514	.8603
400	.0147	.8458	.8605
500	.0216	.8395	.8611
550	.0258	.8346	.8604
662	.0352	.8245	.8597
800	.0476	.8091	.8566
1000	.0679	.7895	.8574
1250	.0978	.7592	.8571
1500	.1271	.7292	.8562
2000	.1910	.6618	.8527
3000	.3135	.5381	.8516
4000	.4059	.4472	.8532
5000	.4725	.3804	.8529
6000	.5251	.3301	.8552
8000	.5931	.2607	.8538
10000	.6368	.2181	.8549

Three LOGARITHMICALLY weighted means of column four :-

No. of Energies	Lower E	Upper E	Average	Reciprocal
27	10	10000	1.5009	.666
20	50	6000	.9510	1.052
17	100	6000	.8686	1.151

midpoint) that it represented. The averaging was carried out over three energy bands, 100 - 6000 keV (17 points), 50 - 6000 keV (20 points), and the full set of values, 10 - 10000 keV (27 points).

Since the partition equation, as used, produces the dose ratios LiF to polystyrene, it is finally necessary to take reciprocals to get the ratios of polystyrene to LiF. These two steps are shown in the small sub-table at the bottom of Table B.3.

B.7 Results of Sensitivity Tests

The results of the sensitivity calculations are given in Table B.4. This shows quite dramatically that only very small changes (a few percent) occur in the mean dose ratios, when the value of P is varied by an order of magnitude (1000 %).

TABLE B.4

Values of mean dose ratios calculated for five settings of the parameter P. For each of the three energy ranges there is a significant lack of sensitivity to P.

Values of P ⟶ / Photon Energy Range (keV) ↓	1.0	0.5	0.2	0.1	0.05
10 - 10,000	.673	.667	.666	.666	.665
50 - 6000	1.070	1.053	1.052	1.050	1.049
100 - 6000	1.174	1.153	1.151	1.150	1.148

It can be concluded that the actual value assigned to P within the range tested is relatively unimportant. It is therefore logical to assign a middle value, say P = 0.2. This leads to the averaged dose ratios already seen at the bottom of Table B.3.

B.8 Derivation of the Exposure to Dose Conversion Factor

Inspection of column four of Table B.3 shows that the dose ratios are almost constant above 150 keV, while considerable changes with energy are seen below 100 keV. It appears from the CDI study that only a very small fraction of dose to Ontario Hydro workers in the nuclear power stations is delivered by low energy photons. When the ratios are averaged with logarithmic energy-interval weighting the results are biased towards the low energy end, as can be seen from Table B.3.

Therefore, when using the logarithmic method, it is appropriate to average only over the energy range of interest, that is from 100 to 6000 keV. As seen in the bottom line of Table B.3, this gives :-

Mean dose ratio polystyrene / LiF = 1.151 (7).

We now consider the chip calibrations for the petty phantom readout. Let the chips read Y light units when given one unit of exposure, and let an unknown field chip give Z light units. Then we can write for this chip :-

$$D_{LiF} = 0.810 \, (Z / Y) \text{ rad} = 0.0081 \, (Z / Y) \text{ Gy} \quad (8),$$

where the numeric terms are the exposure to absorbed dose conversion factor for LiF at 662 keV.

To derive absorbed dose in soft tissue, the mass energy absorption coefficients of muscle and polystyrene were tabulated and their ratio averaged over the same energy range and with the same weighting method discussed earlier in this Appendix. There is very little change with energy, and the following was obtained :-

Mean Ratio, muscle / polystyrene = 1.035 (9).

Combining equations (7), (8) and (9) we can write :-

$$D_{Muscle} = (1.035)\,(0.810)\,(1.151)\,(Z / Y)$$

$$D_{Muscle} = 0.965 \, (Z / Y) \quad \text{rad} \quad (10)$$

$$D_{Muscle} = 0.00965 \, (Z / Y) \quad \text{Gy} \quad (10a)$$

The numerical conversion factor is given for both systems of units. In practice it was the non-SI factor of equation (10) that was used for the present work.

APPENDIX C

Complete Tabulation of All Reported Whole Body (or Deep) Dose Results

Index

Processor	Pages
CRNL	C2 - C6
HWC	C7 - C11
NBEPC	C12 - C16
H-Q	C17 - C21
OH	C22 - C26
All Participants	C27 - C31

CANADIAN DOSIMETRY INTERCOMPARISON 1986

RESULTS OF

CHALK RIVER NUCLEAR LABORATORIES

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF CHALK RIVER BADGE RESULTS

Week Number One (29 September - 3 October)

Bruce Nuclear Generating Station - A

Date 1986	Run Number	Location	Detail	Badge No.	Plaque No.	Whole Body Readings mSv	Whole Body Readings Mean
30 Sept	1	Unit 1 Reactor Vault	E. Reactor Face	4	S-59xx		
				5	S-59xx		
				6	S-59xx		
" "	2	" " "	S-W Feeder Cabinet	1	S-59xx		
				2	S-59xx		
				3	S-59xx		
" "	3	" " "	S-E Feeder Cabinet	7	S-59xx		
				8	S-59xx		
				9	S-59xx		
1 Oct.	4	F/M Serv.Area	Sm. Parts Decontam.	13	S-59xx		
				14	S-59xx		
				15	S-59xx		
" "	5	" " "	S. Ext. Trolley	10	S-59xx		
				11	S-59xx		
				12	S-59xx		
" "	6	Fuelling Machine Duct	Facing towards U-3	16	S-59xx		
				17	S-59xx		
				18	S-59xx		
2-3 Oct	7	U-2 North Wall	Delayed n Mon. Rm.	25	S-5928	2.00	
				26	S-5929	2.00	2.00
				27	S-5930	2.00	
2 Oct	8	U-2 South Wall	Mod.1-X Room	22	S-5925	4.00	
				23	S-5926	4.30	4.13
				24	S-5927	4.10	
" "	9	U-1 Candecon	Floor nr Resin Tank	19	S-5922	5.40	
				20	S-5923	5.30	5.33
				21	S-5924	5.30	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF CHALK RIVER BADGE RESULTS

Week Number Two (14 October - 17 October)

Bruce Nuclear Generating Station - A

Date 1986	Run Number	Location	Detail	Badge No.	Plaque No.	Whole Body Readings mSv	Whole Body Readings Mean
15 Oct.	10	F/H Serv.Area	S. Ext. Trolley	1	S-5935	2.40	
				2	S-5936	2.60	2.50
				3	S-5937	2.50	
" "	11	" " "	" " "	4	S-5938	1.80	
				5	S-5939	1.80	1.80
				6	S-5940	1.80	
" "	12	" " "	" " "	7	S-5941	2.10	
				8	S-5942	2.00	2.10
				9	S-5943	2.20	
" "	13	U-1 Candecon	On Drum	10	S-5944	11.80	
				11	S-5945	11.70	11.80
				12	S-5946	11.90	
" "	14	" "	On Floor	13	S-5947	6.10	
				14	S-5948	6.30	6.23
				15	S-5949	6.30	
" "	15	" "	On Scaffold	16	S-5950	6.90	
				17	S-5951	7.10	7.00
				18	S-5952	7.00	
16 Oct.	16	U-2 South Wall	Mod.I-X Room	19	S-5953	5.50	
				20	S-5954	5.40	5.47
				21	S-5955	5.50	
" "	17	" " "	" " "	22	S-5956	5.30	
				23	S-5957	5.30	5.33
				24	S-5958	5.40	
" "	18	" " "	" " "	25	S-5959	2.70	
				26	S-5960	2.80	2.87
				27	S-5961	3.10	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF CHALK RIVER BADGE RESULTS

Week Number Three (27 October - 31 October)

Pickering Nuclear Generating Station - A & B

Date 1986	Run Number	Location	Detail	Badge No.	Plaque No.	Whole Body Readings mSv	Mean
28-29 O	19	U-6 Boiler Rm.	Bleed Cooler	1	S-5904	4.70	
				2	S-5905	4.90	4.73
				3	S-5906	4.60	
" "	20	" " "	Bleed Condenser	4	S-5907	2.90	
				5	S-5908	2.90	2.87
				6	S-5909	2.80	
" "	21	" " "	Bld.Cdsr.Platform	7	S-5910	14.40	
				8	S-5911	14.30	14.30
				9	S-5912	14.20	
29 Oct.	22	U-3 Cover Gas	Compr.Pipe	13	S-5916	5.50	
				14	S-5917	5.50	5.50
				15	S-5918	5.50	
" "	23	U-4 Mod.Slurry Line	Near Pipe	16	S-5919	13.00	
				17	S-5920	13.70	13.43
				18	S-5921	13.60	
" "	24	U-3 Mod.Slurry Line	Near T-Joint	10	S-5913	8.80	
				11	S-5914	9.90	9.13
				12	S-5915	8.70	
30 Oct.	25	Aux.Irr.Fuel Bay	Side of Flask	19	S-5922	8.70	
				20	S-5923	8.60	8.67
				21	S-5924	8.70	
" "	26	I-X Clean-Up Area	Drum on Floor	25	S-5928	5.40	
				26	S-5929	5.20	5.30
				27	S-5930	5.30	
" "	27	U-3 NE Acc.Area	near CV-22	22	S-5925	6.60	
				23	S-5926	6.80	6.67
				24	S-5927	6.60	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF CHALK RIVER BADGE RESULTS

Week Number Four (17 November - 21 November)

Pickering Nuclear Generating Station - A & B

Date 1986	Run Number	Location	Detail	Badge No.	Plaque No.	Whole Body Readings mSv	Mean
18 Nov.	28	F/H Maint.Shop	Ram Seal Filters	1	S-5935	4.10	
				2	S-5936	4.60	4.40
				3	S-5937	4.50	
" "	29	" " "	Ram Heads	7	S-5941	1.90	
				8	S-5942	2.00	1.93
				9	S-5943	1.90	
" "	30	" " "	Clos.Plug Disks	4	S-5938	3.40	
				5	S-5939	3.30	3.30
				6	S-5940	3.20	
19 Nov.	31	U-3 Mod.Room	Mod. Tanks	10	S-5944	4.00	
				11	S-5945	3.80	3.97
				12	S-5946	4.10	
" "	32	" " "	" "	16	S-5950	4.00	
				17	S-5951	4.20	4.03
				18	S-5952	3.90	
" "	33	" " "	" "	13	S-5947	4.00	
				14	S-5948	4.00	4.00
				15	S-5949	4.00	
20-21 N	34	U-6 Reactor Vault	E. Reactor Face	19	S-5953	8.10	
				20	S-5954	8.00	8.07
				21	S-5955	8.10	
" "	35	" " "	E. Feeder Cab.	25	S-5959	13.70	
				26	S-5960	13.60	13.90
				27	S-5961	14.40	
" "	36	" " "	E.Reactor Face	22	S-5956	6.00	
				23	S-5957	6.20	6.03
				24	S-5958	5.90	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

RESULTS OF

DEPARTMENT OF NATIONAL HEALTH AND WELFARE

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF . HEALTH & WELFARE CANADA RESULTS

Week Number One (29 September - 3 October)

Bruce Nuclear Generating Station - A

Date 1986	Run Number	Location	Detail	Badge No.	Plaque No.	Whole Body Readings mSv	Mean
30 Sept	1	Unit 1 Reactor Vault	E. Reactor Face	4	230004	1.10	
				5	230005	1.20	1.17
				6	230006	1.20	
" "	2	" " "	S-W Feeder Cabinet	1	230001	0.70	
				2	230002	0.70	0.70
				3	230003	0.70	
" "	3	" " "	S-E Feeder Cabinet	7	230007	0.90	
				8	230008	0.70	0.80
				9	230009	0.80	
1 Oct.	4	F/M Serv.Area	Sm. Parts Decontam.	13	230013	3.00	
				14	230014	2.90	2.93
				15	230015	2.90	
" "	5	" " "	S. Ext. Trolley	10	230010	4.20	
				11	230011	4.10	4.07
				12	230012	3.90	
" "	6	Fuelling Machine Duct	Facing towards U-3	16	230016	2.80	
				17	230017	2.80	2.87
				18	230018	3.00	
2-3 Oct	7	U-2 North Wall	Delayed n Mon. Rm.	25	230025	2.80	
				26	230026	2.60	2.70
				27	230027	2.70	
2 Oct	8	U-2 South Wall	Mod.I-X Room	22	230022	5.70	
				23	230023	5.40	5.70
				24	230024	6.00	
" "	9	U-1 Candecon	Floor nr Resin Tank	19	230019	6.80	
				20	230020	7.40	7.20
				21	230021	7.40	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF HEALTH & WELFARE CANADA RESULTS

Week Number Two (14 October - 17 October)

Bruce Nuclear Generating Station - A

Date 1986	Run Number	Location	Detail	Badge No.	Plaque No.	Whole Body Readings mSv	Whole Body Readings Mean
15 Oct.	10	F/H Serv.Area	S. Ext. Trolley	1	230037	3.20	
				2	230038	3.40	3.37
				3	230039	3.50	
" "	11	" " "	" " "	4	230040	2.50	
				5	230041	2.60	2.57
				6	230042	2.60	
" "	12	" " "	" " "	7	230043	3.10	
				8	230044	2.70	2.93
				9	230045	3.00	
" "	13	U-1 Candecon	On Drum	10	230046	17.50	
				11	230047	19.10	18.63
				12	230048	19.30	
" "	14	" "	On Floor	13	230049	10.00	
				14	230050	9.50	10.03
				15	230051	10.60	
" "	15	" "	On Scaffold	16	230052	11.20	
				17	230053	9.70	10.70
				18	230054	11.20	
16 Oct.	16	U-2 South Wall	Mod.I-X Room	19	230055	9.30	
				20	230056	8.70	8.83
				21	230057	8.50	
" "	17	" " "	" " "	22	230058	8.90	
				23	230059	8.20	8.63
				24	230060	8.80	
" "	18	" " "	" " "	25	230061	4.50	
				26	230062	4.80	4.73
				27	230063	4.90	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF HEALTH & WELFARE CANADA RESULTS

Week Number Three (27 October - 31 October)

Pickering Nuclear Generating Station - A & B

Date 1986	Run Number	Location	Detail	Badge No.	Plaque No.	Whole Body mSv	Readings Mean
28-29 O	19	U-6 Boiler Rm.	Bleed Cooler	1	230075	6.10	
				2	230076	5.60	5.80
				3	230077	5.70	
" "	20	" " "	Bleed Condenser	4	230078	3.90	
				5	230079	3.60	3.63
				6	230080	3.40	
" "	21	" " "	Bld.Cdsr.Platform	7	230081	19.50	
				8	230082	18.00	18.57
				9	230083	18.20	
29 Oct.	22	U-3 Cover Gas	Compr.Pipe	13	230087	11.60	
				14	230088	10.20	10.70
				15	230089	10.30	
" "	23	U-4 Mod.Slurry Line	Near Pipe	16	230090	16.60	
				17	230091	16.80	16.57
				18	230092	16.30	
" "	24	U-3 Mod.Slurry Line	Near T-Joint	10	230084	6.60	
				11	230085	7.00	6.93
				12	230086	7.20	
30 Oct.	25	Aux.Irr.Fuel Bay	Side of Flask	19	230093	10.90	
				20	230094	11.20	10.70
				21	230095	10.00	
" "	26	I-X Clean-Up Area	Drum on Floor	25	230098	6.90	
				26	230099	6.60	6.67
				27	230100	6.50	
" "	27	U-3 NE Acc.Area	near CV-22	22	230096	7.80	
				23	230097	8.10	7.95
				24	2300xx	7.95	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF HEALTH & WELFARE CANADA RESULTS

Week Number Four (17 November - 21 November)

Pickering Nuclear Generating Station - A & B

Date 1986	Run Number	Location	Detail	Badge No.	Plaque No.	Whole Body Readings mSv	Whole Body Readings Mean
18 Nov.	28	F/M Maint.Shop	Ram Seal Filters	1	230001	4.50	
				2	230002	4.50	4.47
				3	230003	4.40	
" "	29	" " "	Ram Heads	7	230007	2.00	
				8	230008	2.10	2.00
				9	230009	1.90	
" "	30	" " "	Clos.Plug Disks	4	230004	3.00	
				5	230005	3.70	3.30
				6	230006	3.20	
19 Nov.	31	U-3 Mod.Room	Mod. Tanks	10	230010	4.20	
				11	230011	4.30	4.30
				12	230012	4.40	
" "	32	" " "	" "	16	230016	4.40	
				17	230017	4.70	4.47
				18	230018	4.30	
" "	33	" " "	" "	13	230013	4.40	
				14	230014	5.00	4.53
				15	230015	4.20	
20-21 N	34	U-6 Reactor Vault	E. Reactor Face	19	230019	8.60	
				20	230020	8.70	8.87
				21	230021	9.30	
" "	35	" " "	E. Feeder Cab.	25	230025	16.10	
				26	230026	14.70	15.50
				27	230027	15.70	
" "	36	" " "	E.Reactor Face	22	230022	6.70	
				23	230023	6.70	6.80
				24	230024	7.00	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

RESULTS OF

NEW BRUNSWICK ELECTRIC POWER COMMISSION

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF NEW BRUNSWICK ELECTRIC RESULTS

Week Number One (29 September - 3 October)

Bruce Nuclear Generating Station - A

Date	Run	Location	Detail	Badge	Deep Dose Readings	
1986	Number			No.	mSv	Mean
30 Sept	1	Unit 1 Reactor Vault	E. Reactor Face	4	0.72	
				5	0.70	0.70
				6	0.69	
" "	2	" " "	S-W Feeder Cabinet	1	0.45	
				2	0.45	0.46
				3	0.47	
" "	3	" " "	S-E Feeder Cabinet	7	0.50	
				8	0.45	0.51
				9	0.59	
1 Oct.	4	F/M Serv.Area	Sm. Parts Decontam.	13	1.91	
				14	2.10	1.96
				15	1.88	
" "	5	" " "	S. Ext. Trolley	10	2.02	
				11	2.13	2.24
				12	2.56	
" "	6	Fuelling Machine Duct	Facing towards U-3	16	2.00	
				17	1.91	1.96
				18	1.98	
2-3 Oct	7	U-2 North Wall	Delayed n Mon. Rm.	25	1.82	
				26	1.85	1.83
				27	1.82	
2 Oct	8	U-2 South Wall	Mod.I-X Room	22	3.64	
				23	3.86	3.66
				24	3.47	
" "	9	U-1 Candecon	Floor nr Resin Tank	19	4.78	
				20	4.78	4.78
				21	4.77	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF NEW BRUNSWICK ELECTRIC RESULTS

Week Number Two (14 October - 17 October)

Bruce Nuclear Generating Station - A

Date	Run	Location	Detail	Badge	Deep Dose Readings	
1986	Number			No.	mSv	Mean
15 Oct.	10	F/M Serv.Area	S. Ext. Trolley	1	2.59	
				2	2.64	2.58
				3	2.50	
" "	11	" " "	" " "	4	1.58	
				5	1.96	1.80
				6	1.85	
" "	12	" " "	" " "	7	2.45	
				8	2.23	2.33
				9	2.32	
" "	13	U-1 Candecon	On Drum	10	13.94	
				11	12.74	12.46
				12	10.71	
" "	14	" "	On Floor	13	7.49	
				14	6.71	7.01
				15	6.83	
" "	15	" "	On Scaffold	16	8.29	
				17	8.33	8.04
				18	7.49	
16 Oct.	16	U-2 South Wall	Mod.1-X Room	19	5.77	
				20	6.03	5.94
				21	6.01	
" "	17	" " "	" " "	22	5.91	
				23	6.22	5.96
				24	5.74	
" "	18	" " "	" " "	25	2.79	
				26	3.09	2.94
				27	2.94	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF NEW BRUNSWICK ELECTRIC RESULTS

Week Number Three (27 October - 31 October)

Pickering Nuclear Generating Station - A & B

Date	Run	Location	Detail	Badge	Deep Dose Readings	
1986	Number			No.	mSv	Mean
28-29 O	19	U-6 Boiler Rm.	Bleed Cooler	1	4.32	
				2	4.61	4.38
				3	4.20	
" "	20	" " "	Bleed Condenser	4	2.72	
				5	2.79	2.72
				6	2.66	
" "	21	" " "	Bld.Cdsr.Platform	7	13.72	
				8	12.33	13.53
				9	14.53	
29 Oct.	22	U-3 Cover Gas	Compr.Pipe	13	7.55	
				14	8.61	7.99
				15	7.81	
" "	23	U-4 Mod.Slurry Line	Near Pipe	16	14.51	
				17	13.33	13.85
				18	13.72	
" "	24	U-3 Mod.Slurry Line	Near T-Joint	10	4.24	
				11	4.41	4.59
				12	5.11	
30 Oct.	25	Aux.Irr.Fuel Bay	Side of Flask	19	8.17	
				20	8.67	8.44
				21	8.49	
" "	26	1-X Clean-Up Area	Drum on Floor	25	5.28	
				26	5.27	5.22
				27	5.12	
" "	27	U-3 NE Acc.Area	near CV-22	22	6.35	
				23	6.61	6.38
				24	5.95	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF NEW BRUNSWICK ELECTRIC RESULTS

Week Number Four (17 November - 21 November)

Pickering Nuclear Generating Station - A & B

Date	Run	Location	Detail	Badge	Deep Dose Readings	
1986	Number			No.	mSv	Mean
18 Nov.	28	F/M Maint.Shop	Ram Seal Filters	1	2.10	
				2	2.25	2.06
				3	1.82	
" "	29	" " "	Ram Heads	7	3.17	
				8	2.37	2.79
				9	2.84	
" "	30	" " "	Clos.Plug Disks	4	3.71	
				5	4.99	4.42
				6	4.57	
19 Nov.	31	U-3 Mod.Room	Mod. Tanks	10	5.29	
				11	4.29	4.13
				12	2.80	
" "	32	" " "	" "	16	5.90	
				17	5.68	5.32
				18	4.37	
" "	33	" " "	" "	13	5.54	
				14	4.47	4.84
				15	4.52	
20-21 N	34	U-6 Reactor Vault	E. Reactor Face	19	8.85	
				20	9.46	9.43
				21	9.99	
" "	35	" " "	E. Feeder Cab.	25	12.46	
				26	16.31	14.96
				27	16.11	
" "	36	" " "	E.Reactor Face	22	7.37	
				23	9.81	7.87
				24	7.23	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

RESULTS OF

HYDRO-QUÉBEC

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF HYDRO QUÉBEC BADGE RESULTS

Week Number One (29 September - 3 October)

Bruce Nuclear Generating Station - A

Date 1986	Run Number	Location	Detail	Badge No.	Plaque No.	Whole Body Readings mSv	Whole Body Readings Mean
30 Sept	1	Unit 1 Reactor Vault	E. Reactor Face	4	A-0921	0.87	
				5	A-0922	0.80	0.86
				6	A-0926	0.90	
" "	2	" " "	S-W Feeder Cabinet	1	A-0912	0.61	
				2	A-0915	0.57	0.58
				3	A-0916	0.55	
" "	3	" " "	S-E Feeder Cabinet	7	A-0927	0.60	
				8	A-0928	0.59	0.59
				9	A-0929	0.59	
1 Oct.	4	F/M Serv.Area	Sa. Parts Decontam.	13	A-0941	2.39	
				14	A-0943	2.31	2.37
				15	A-0948	2.40	
" "	5	" " "	S. Ext. Trolley	10	A-0936	2.90	
				11	A-0938	2.86	2.87
				12	A-0940	2.84	
" "	6	Fuelling Machine Duct	Facing towards U-3	16	A-0949	2.23	
				17	A-0950	2.03	2.17
				18	A-0951	2.24	
2-3 Oct	7	U-2 North Wall	Delayed n Mon. Rm.	25	A-0973	2.21	
				26	A-0974	2.28	2.24
				27	A-0977	2.23	
2 Oct	8	U-2 South Wall	Mod.1-X Room	22	A-0960	4.43	
				23	A-0965	4.49	4.47
				24	A-0972	4.49	
" "	9	U-1 Candecon	Floor nr Resin Tank	19	A-0952	5.57	
				20	A-0955	5.60	5.59
				21	A-0957	5.53	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF HYDRO QUÉBEC BADGE RESULTS

Week Number Two (14 October - 17 October)

Bruce Nuclear Generating Station - A

Date 1986	Run Number	Location	Detail	Badge No.	Plaque No.	Whole Body Readings mSv	Mean
15 Oct.	10	F/H Serv.Area	S. Ext. Trolley	1	B-0904	2.50	
				2	B-0905	2.56	2.50
				3	B-0907	2.44	
" "	11	" " "	" " "	4	B-0908	1.80	
				5	B-0911	1.91	1.86
				6	B-0914	1.86	
" "	12	" " "	" " "	7	B-0915	2.27	
				8	B-0916	2.25	2.2.
				9	B-0917	2.25	
" "	13	U-1 Candecon	On Drum	10	B-0923	13.61	
				11	B-0925	13.68	13.61
				12	B-0926	13.55	
" "	14	" "	On Floor	13	B-0929	7.41	
				14	B-0930	7.45	7.39
				15	B-0933	7.31	
" "	15	" "	On Scaffold	16	B-0934	8.33	
				17	B-0935	8.08	8.16
				18	B-0938	8.07	
16 Oct.	16	U-2 South Wall	Mod.I-X Room	19	B-0937	6.58	
				20	B-0944	6.21	6.50
				21	B-0952	6.71	
" "	17	" " "	" " "	22	B-0956	6.39	
				23	B-0959	6.29	6.31
				24	B-0962	6.25	
" "	18	" " "	" " "	25	B-0963	3.48	
				26	B-0964	3.45	3.47
				27	B-0965	3.48	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF HYDRO QUÉBEC BADGE RESULTS

Week Number Three (27 October - 31 October)

Pickering Nuclear Generating Station - A & B

Date 1986	Run Number	Location	Detail	Badge No.	Plaque No.	Whole Body Readings mSv	Mean
28-29 O	19	U-6 Boiler Rm.	Bleed Cooler	1	A-0912	5.48	
				2	A-0915	5.47	5.44
				3	A-0916	5.38	
" "	20	" " "	Bleed Condenser	4	A-0921	3.39	
				5	A-0922	3.16	3.33
				6	A-0926	3.44	
" "	21	" " "	Bld.Cdsr.Platform	7	A-0927	15.85	
				8	A-0928	16.11	15.94
				9	A-0929	15.87	
29 Oct.	22	U-3 Cover Gas	Compr.Pipe	13	A-0936	6.60	
				14	A-0938	6.60	6.58
				15	A-0940	6.54	
" "	23	U-4 Mod.Slurry Line	Near Pipe	16	A-0949	15.33	
				17	A-0950	14.43	15.00
				18	A-0951	15.25	
" "	24	U-3 Mod.Slurry Line	Near T-Joint	10	A-0941	9.91	
				11	A-0943	10.10	10.09
				12	A-0948	10.25	
30 Oct.	25	Aux.Irr.Fuel Bay	Side of Flask	19	A-0952	9.59	
				20	A-0955	9.85	9.64
				21	A-0957	9.48	
" "	26	I-X Clean-Up Area	Drum on Floor	25	A-0973	6.30	
				26	A-0974	6.38	6.29
				27	A-0977	6.19	
" "	27	U-3 NE Acc.Area	near CV-22	22	A-0960	7.65	
				23	A-0965	7.76	7.67
				24	A-0972	7.60	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF HYDRO QUÉBEC BADGE RESULTS

Week Number Four (17 November - 21 November)

Pickering Nuclear Generating Station - A & B

Date 1986	Run Number	Location	Detail	Badge No.	Plaque No.	Whole Body Readings mSv	Mean
18 Nov.	28	F/M Maint.Shop	Ram Seal Filters	1	B-0904	3.73	
				2	B-0905	3.49	3.55
				3	B-0907	3.42	
" "	29	" " "	Ram Heads	7	B-0915	2.81	
				8	B-0916	1.98	1.99
				9	B-0917	1.97	
" "	30	" " "	Clos.Plug Disks	4	B-0908	3.50	
				5	B-0911	3.57	3.50
				6	B-0914	3.44	
19 Nov.	31	U-3 Mod.Room	Mod. Tanks	10	B-0923	4.15	
				11	B-0925	4.28	4.24
				12	B-0926	4.30	
" "	32	" " "	" "	16	B-0934	4.51	
				17	B-0935	4.41	4.47
				18	B-0937	4.48	
" "	33	" " "	" "	13	B-0929	4.52	
				14	B-0930	4.50	4.48
				15	B-0933	4.41	
20-21 N	34	U-6 Reactor Vault	E. Reactor Face	19	B-0938	9.34	
				20	B-0944	9.19	9.38
				21	B-0952	9.60	
" "	35	" " "	E. Feeder Cab.	25	B-0963	15.94	
				26	B-0964	15.96	15.96
				27	B-0965	15.99	
" "	36	" " "	E.Reactor Face	22	B-0956	7.24	
				23	B-0959	7.18	7.20
				24	B-0962	7.18	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

RESULTS OF

ONTARIO HYDRO

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF ONTARIO HYDRO BADGE RESULTS

Week Number One (29 September - 3 October)

Bruce Nuclear Generating Station - A

Date 1986	Run Number	Location	Detail	Badge No.	Plaque No.	Whole Body mSv	Readings Mean
30 Sept	1	Unit 1 Reactor Vault	E. Reactor Face	4	E0017	0.75	
				5	E0020	0.75	0.77
				6	E0021	0.80	
" "	2	" " "	S-W Feeder Cabinet	1	E0013	0.50	
				2	E0014	0.45	0.47
				3	E0015	0.45	
" "	3	" " "	S-E Feeder Cabinet	7	E0023	0.55	
				8	E0024	0.50	0.53
				9	E0026	0.55	
1 Oct.	4	F/M Serv.Area	Sm. Parts Decontam.	13	E0030	2.15	
				14	E0031	2.10	2.13
				15	E0032	2.15	
" "	5	" " "	S. Ext. Trolley	10	E0027	2.55	
				11	E0028	2.65	2.60
				12	E0029	2.60	
" "	6	Fuelling Machine Duct	Facing towards U-3	16	E0033	2.00	
				17	E0034	2.15	2.03
				18	E0035	1.95	
2-3 Oct	7	U-2 North Wall	Delayed n Mon. Rm.	25	E0043	2.05	
				26	E0045	2.00	2.03
				27	E0046	2.05	
2 Oct	8	U-2 South Wall	Mod.1-X Room	22	E0040	4.20	
				23	E0041	4.40	4.33
				24	E0042	4.40	
" "	9	U-1 Candecon	Floor nr Resin Tank	19	E0037	5.40	
				20	E0038	5.40	5.38
				21	E0039	5.35	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF ONTARIO HYDRO BADGE RESULTS

Week Number Two (14 October - 17 October)

Bruce Nuclear Generating Station - A

Date 1986	Run Number	Location	Detail	Badge No.	Plaque No.	Whole Body mSv	Readings Mean
15 Oct.	10	F/H Serv.Area	S. Ext. Trolley	1	E0014	2.10	
				2	E0015	2.00	2.05
				3	E0017	2.05	
" "	11	" " "	" " "	4	E0020	1.55	
				5	E0021	1.55	1.55
				6	E0023	1.55	
" "	12	" " "	" " "	7	E0024	1.80	
				8	E0027	1.85	1.82
				9	E0028	1.80	
" "	13	U-1 Candecon	On Drum	10	E0029	11.70	
				11	E0031	11.45	11.55
				12	E0032	11.50	
" "	14	" "	On Floor	13	E0033	6.15	
				14	E0037	6.40	6.33
				15	E0038	6.45	
" "	15	" "	On Scaffold	16	E0039	7.05	
				17	E0040	6.95	7.03
				18	E0041	7.10	
16 Oct.	16	U-2 South Wall	Mod.1-X Room	19	E0042	5.65	
				20	E0045	5.50	5.53
				21	E0046	5.45	
" "	17	" " "	" " "	22	E0047	5.50	
				23	E0049	5.45	5.48
				24	E0050	5.50	
" "	18	" " "	" " "	25	E0051	2.95	
				26	E0052	2.90	2.93
				27	E0054	2.95	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF ONTARIO HYDRO BADGE RESULTS

Week Number Three (27 October - 31 October)

Pickering Nuclear Generating Station - A & B

Date 1986	Run Number	Location	Detail	Badge No.	Plaque No.	Whole Body mSv	Readings Mean
28-29 O	19	U-6 Boiler Rm.	Bleed Cooler	1	E0014	4.80	
				2	E0015	4.40	4.55
				3	E0017	4.45	
" "	20	" " "	Bleed Condenser	4	E0020	2.70	
				5	E0021	2.80	2.80
				6	E0023	2.90	
" "	21	" " "	Bld.Cdsr.Platform	7	E0024	14.25	
				8	E0027	13.50	14.13
				9	E0028	14.65	
29 Oct.	22	U-3 Cover Gas	Compr.Pipe	10	E0029	5.90	
				11	E0031	5.75	5.70
				12	E0032	5.70	
" "	23	U-4 Mod.Slurry Line	Near Pipe	16	E0039	13.30	
				17	E0040	13.30	13.55
				18	E0041	14.05	
" "	24	U-3 Mod.Slurry Line	Near T-Joint	13	E0033	8.55	
				14	E0037	8.95	8.83
				15	E0038	9.00	
30 Oct.	25	Aux.Irr.Fuel Bay	Side of Flask	19	E0042	8.65	
				20	E0045	8.45	8.48
				21	E0046	8.35	
" "	26	I-X Clean-Up Area	Drum on Floor	25	E0052	5.35	
				26	E0054	5.50	5.37
				27	E0055	5.25	
" "	27	U-3 NE Acc.Area	near CV-22	22	E0049	6.65	
				23	E0050	6.85	6.68
				24	E0051	6.55	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

TABULATION OF ONTARIO HYDRO BADGE RESULTS

Week Number Four (17 November - 21 November)

Pickering Nuclear Generating Station - A & B

Date 1986	Run Number	Location	Detail	Badge No.	Plaque No.	Whole Body mSv	Readings Mean
18 Nov.	28	F/H Maint.Shop	Ram Seal Filters	1	E0015	3.50	
				2	E0017	3.35	3.35
				3	E0020	3.20	
" "	29	" " "	Ram Heads	7	E0029	1.85	
				8	E0031	1.75	1.78
				9	E0032	1.75	
" "	30	" " "	Clos.Plug Disks	4	E0021	3.20	
				5	E0023	3.25	3.17
				6	E0060	3.05	
19 Nov.	31	U-3 Mod.Room	Mod. Tanks	10	E0033	3.65	
				11	E0035	3.55	3.67
				12	E0037	3.80	
" "	32	" " "	" "	16	E0045	3.85	
				17	E0046	3.80	3.85
				18	E0047	3.90	
" "	33	" " "	" "	13	E0038	4.00	
				14	E0041	3.95	3.97
				15	E0042	3.95	
20-21 N	34	U-6 Reactor Vault	E. Reactor Face	19	E0049	8.35	
				20	E0050	8.40	8.30
				21	E0051	8.15	
" "	35	" " "	E. Feeder Cab.	25	E0056	13.80	
				26	E0057	13.85	13.93
				27	E0058	14.15	
" "	36	" " "	E.Reactor Face	22	E0052	6.15	
				23	E0054	6.40	6.30
				24	E0055	6.35	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

RESULTS OF

ALL PARTICIPANTS

CANADIAN DOSIMETRY INTERCOMPARISON 1986

THESE TABLES SHOW REPORTED DOSE AND NORMALIZED DOSE RATIOS BASED ON rad / R = .965

BRACKETS (D.D) SHOW RESULTS NORMALIZED BY PETTY PHANTOM DEPTH - DOSES AT 1000 mg/cmq

Week Number One (29 September - 3 October)

Bruce Nuclear Generating Station - A

Date 1986	Run Number	Location	CRNL	NRNC	NBEPC
WHOLE BODY, OR DEEP :-			------- UNITS - mSv (Brackets give Normalized Ratio) --------		
30 Sept	1	Unit 1 Reactor Vault	0.00 (0.00)	1.17 (1.42)	0.70 (0.85)
" "	2	" " "	0.00 (0.00)	0.70 (1.33)	0.46 (0.87)
" "	3	" " "	0.00 (0.00)	0.80 (1.31)	0.51 (0.84)
1 Oct.	4	F/M Serv.Area	0.00 (0.00)	2.93 (1.30)	1.96 (0.87)
" "	5	" " "	0.00 (0.00)	4.07 (1.82)	2.24 (1.00)
" "	6	Fuelling Machine Duct	0.00 (0.00)	2.87 (1.39)	1.96 (0.95)
2-3 Oct	7	U-2 North Wall	2.00 (0.93)	2.70 (1.26)	1.83 (0.85)
2 Oct	8	U-2 South Wall	4.13 (0.96)	5.70 (1.32)	3.66 (0.85)
" "	9	U-1 Candecon	5.33 (0.97)	7.20 (1.31)	4.78 (0.87)
			H-Q	O-H	
	1		0.86 (1.04)	0.77 (0.93)	
	2		0.58 (1.10)	0.47 (0.89)	
	3		0.59 (0.97)	0.53 (0.87)	N.B. CRNL was unable
	4		2.37 (1.04)	2.13 (0.94)	to participate in runs
	5		2.87 (1.28)	2.60 (1.16)	number 1 - 6.
	6		2.17 (1.05)	2.03 (0.99)	
	7		2.24 (1.05)	2.03 (0.95)	
	8		4.47 (1.03)	4.33 (1.00)	
	9		5.59 (1.02)	5.38 (0.98)	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

THESE TABLES SHOW REPORTED DOSE AND NORMALIZED DOSE RATIOS BASED ON rad / R = .965

BRACKETS (D.D) SHOW RESULTS NORMALIZED BY PETTY PHANTOM DEPTH - DOSES AT 1000 mg/cmsq

Week Number Two (14 October - 17 October)

Bruce Nuclear Generating Station - A

Date 1986	Run Number	Location	CRNL	N&WC	NBEPC
WHOLE BODY, OR DEEP :-			------- UNITS - mSv (Brackets give Normalized Ratio) --------		
15 Oct.	10	F/N Serv.Area	2.50 (1.53)	3.37 (2.06)	2.58 (1.57)
" "	11	" " "	1.80 (1.53)	2.57 (2.18)	1.80 (1.53)
" "	12	" " "	2.10 (1.62)	2.93 (2.26)	2.33 (1.80)
" "	13	U-1 Candecon	11.80 (0.94)	18.63 (1.49)	12.46 (0.99)
" "	14	" "	6.23 (0.95)	10.03 (1.52)	7.01 (1.06)
" "	15	" "	7.00 (0.96)	10.70 (1.47)	8.04 (1.11)
16 Oct.	16	U-2 South Wall	5.47 (0.93)	8.83 (1.50)	5.94 (1.01)
" "	17	" " "	5.33 (0.95)	8.63 (1.54)	5.96 (1.06)
" "	18	" " "	2.87 (0.92)	4.73 (1.52)	2.94 (0.94)
			H-Q	O-H	
	10		2.50 (1.53)	2.05 (1.25)	
	11		1.86 (1.58)	1.55 (1.32)	
	12		2.26 (1.74)	1.82 (1.40)	
	13		13.61 (1.09)	11.55 (0.92)	
	14		7.39 (1.12)	6.33 (0.96)	
	15		8.16 (1.12)	7.03 (0.97)	
	16		6.50 (1.11)	5.53 (0.94)	
	17		6.31 (1.13)	5.48 (0.98)	
	18		3.47 (1.11)	2.93 (0.94)	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

THESE TABLES SHOW REPORTED DOSE AND NORMALIZED DOSE RATIOS BASED ON rad / R = .965

BRACKETS (D.D) SHOW RESULTS NORMALIZED BY PETTY PHANTOM DEPTH - DOSES AT 1000 mg/cmsq

Week Number Three (27 October - 31 October)

Pickering Nuclear Generating Station - A & B

Date 1986	Run Number	Location	CRNL	NRWC	NBEPC
WHOLE BODY, OR DEEP :-			------- UNITS - mSv (Brackets give Normalized Ratio) --------		
28-29 O	19	U-6 Boiler Rm.	4.73 (0.89)	5.80 (1.09)	4.38 (0.82)
" "	20	" " "	2.87 (0.87)	3.63 (1.10)	2.72 (0.82)
" "	21	" " "	14.30 (0.96)	18.57 (1.24)	13.53 (0.90)
29 Oct.	22	U-3 Cover Gas	5.50 (0.86)	10.70 (1.67)	7.99 (1.25)
" "	23	U-4 Mod.Slurry Line	13.43 (0.95)	16.57 (1.17)	13.85 (0.98)
" "	24	U-3 Mod.Slurry Line	9.13 (0.97)	6.93 (0.74)	4.59 (0.49)
30 Oct.	25	Aux.Irr.Fuel Bay	8.67 (0.93)	10.70 (1.15)	8.44 (0.91)
" "	26	I-X Clean-Up Area	5.30 (0.93)	6.67 (1.16)	5.22 (0.91)
" "	27	U-3 NE Acc.Area	6.67 (0.88)	7.95 (1.05)	6.30 (0.83)
			N-Q	O-N	
	19		5.44 (1.02)	4.55 (0.86)	
	20		3.33 (1.01)	2.80 (0.85)	
	21		15.94 (1.07)	14.13 (0.94)	
	22		6.58 (1.03)	5.78 (0.90)	
	23		15.88 (1.06)	13.55 (0.96)	
	24		10.09 (1.07)	8.83 (0.94)	
	25		9.64 (1.04)	8.48 (0.91)	
	26		6.29 (1.10)	5.37 (0.94)	
	27		7.67 (1.01)	6.68 (0.88)	

CANADIAN DOSIMETRY INTERCOMPARISON 1986

THESE TABLES SHOW REPORTED DOSE AND NORMALIZED DOSE RATIOS BASED ON rad / R = .965

BRACKETS (D.D) SHOW RESULTS NORMALIZED BY PETTY PHANTOM DEPTH - DOSES AT 1000 mg/cmq

Week Number Four (17 November - 21 November)

Pickering Nuclear Generating Station - A & B

Date 1986	Run Number	Location	CRNL	N&MC	NBEPC
WHOLE BODY, OR DEEP :-			------- UNITS - mSv (Brackets give Normalized Ratio) --------		
18 Nov.	28	F/N Maint.Shop	4.40 (2.90)	4.47 (2.95)	2.06 (1.36)
" "	29	" " "	1.93 (0.00)	2.00 (0.00)	2.79 (0.00)
" "	30	" " "	3.30 (0.00)	3.30 (0.00)	4.42 (0.00)
19 Nov.	31	U-3 Mod.Room	3.97 (1.03)	4.30 (1.12)	4.13 (1.07)
" "	32	" " "	4.03 (1.02)	4.47 (1.13)	5.32 (1.35)
" "	33	" " "	4.00 (0.96)	4.53 (1.09)	4.84 (1.17)
20-21 N	34	U-6 Reactor Vault	8.07 (0.89)	8.87 (0.98)	9.43 (1.04)
" "	35	" " "	13.90 (0.98)	15.50 (1.09)	14.96 (1.05)
" "	36	" " "	6.03 (0.88)	6.80 (0.99)	7.87 (1.15)
			N-Q	O-N	
	28		3.55 (2.34)	3.35 (2.21)	
	29		1.99 (0.00)	1.78 (0.00)	
	30		3.50 (0.00)	3.17 (0.00)	N.B. Petty Phantom
	31		4.24 (1.10)	3.67 (0.95)	results for Runs 29 and
	32		4.47 (1.13)	3.85 (0.98)	30 are unavailable.
	33		4.48 (1.08)	3.97 (0.96)	
	34		9.38 (1.03)	8.30 (0.91)	
	35		15.96 (1.13)	13.93 (0.98)	
	36		7.20 (1.05)	6.30 (0.92)	

APPENDIX D
CALCULATION OF ERRORS FOR TLD READOUT MEASUREMENTS

D.1 Systematic Errors

Systematic errors in the dosimetry of the CDI experiment begin with the calibration of a standard gamma source at NRC, Ottawa. The next step is to calibrate a user's ionization chamber as a transfer standard. There is then a chain of errors at each successive step leading to a final measurement of dose on a phantom.

The combined errors in the calibration of a transfer standard at NRC are believed to be in the range of ±2% to ±4% (Jones 1983). The use of the transfer device to calibrate an Ontario Hydro source, and to proceed to the readout of a set of TLDs constitute further steps which sum into the range of ±6% to ±8%. We assume a mean value in each case, giving ±3% for the NRC steps, and ±7% for the OH steps.

D.2 Random Errors

Statistical errors were estimated from the readout of TLD data for the Quality Control Program. This involved the readout of 699 badges on an automatic TLD reader at SSD, Pickering, for the months of January to May, 1988. This procedure would match the readout of the CDI badges of Ontario Hydro. The match is not as good for the manual readout of loose chips from the petty phantoms. However, it was assumed for present purposes that because of the care exercised in manual readout of important data, the probable error of the manual work would not exceed that of the automatic reader.

For each QC run of 35 exposed badges, the deviation of the reading from the exposure was expressed as a mean percentage and a coefficient of variation (i.e., standard deviation expressed as a percentage). These data were then summed, and expressed as a mean for 20 runs. The results gave 0.64 (±3.9) as the mean percent deviation. The minimum and maximum values of percent deviation of the means in the original table were -9.75% and +6.13%. The mean of the CVs was 6.3% (minimum and maximum values of CV were 2.45% and 10.3%).

From the above, it is assumed that 6% (the mean value) is the anticipated percent standard deviation for the badge TLD plaques read out in batches of 35. The same value (6%) is assumed to apply for the petty phantom readouts. Actual batch sizes for reading the petty phantom chips were 36.

D.3 Summation

The systematic and statistical errors include source errors (±3%), transfer errors (±7%), and random TLD errors (±6%). Combining these errors in quadrature gives a total error of ±10% for one standard deviation.

APPENDIX E
A DESCRIPTION OF DOSIMETRY METHODS IN CANADA

E.1 ATOMIC ENERGY OF CANADA LIMITED

E.1.1 Description of the Dosimeter

The dosimeter comprises two plaque mounted TLDs contained within a holder. The plaque identifies the TLDs for the purposes of data handling and for correction for the variation in sensitivity. One dosimeter 0.89 mm thick is used to measure the whole body dose and a second, 0.28 mm thick, is used for surface dosimetry. The holder covers the thicker TLD with 540 mg cm^{-2} of aluminum and the thinner with 7 mg cm^{-2} of tape.

Both TLDs are made from sensitized LiF. The thick TLD contains lithium with a natural isotopic concentration (7% Li^6, 93% Li^7). In the thinner one, the isotope is Li^7. Because of the high thermal neutron cross section of Li^6, a substantially higher dose recorded in the TLD is an indication of thermal neutron dose.

The dosimeters are normally worn on the trunk, centre line, and in the region from the waist to the diaphragm. If there are reasons for believing that very non-uniform irradiation will occur, then it is worn at the position where the highest exposure is expected.

E.1.2 System Calibration

Standard dosimeters are exposed to 1.15 R of Co-60 gamma rays. The surface dosimeters are covered with 320 mg cm^{-2} of aluminum (only during calibration) to provide electronic equilibrium. These dosimeters are then used in the calculation of doses from the readings obtained from dosimeters worn by workers and visitors to CRNL.

E.1.3 Interpretation of the Readings

Doses are calculated by comparison of the readings of the dosimeters worn by the potentially exposed and those of the standard dosimeters as follows:

$$\text{Dose} = \frac{(r\text{-}B)' - (R\{0\} - B)'}{(R\{1\} - B)' - (R\{0\} - B)'} \cdot 1$$

The symbol · implies division by the individual calibration factor for a TLD.
r is the reading of the dosimeter.
B is the mean reading of the background dosimeters which have been read twice.
R{0} is the mean reading of background dosimeters which have been exposed to background radiation except during the working week.
R{1} is the mean reading of dosimeters exposed to 1.15 R.

Implicit in this formula is the assumption that if a dosimeter, properly worn at the time of radiation, is exposed to 1.15 R, the wearer will receive an effective dose equivalent of 10 mSv (1 rem).

The basis of this assumption has been rather extensively discussed during the meetings of the AECB ad hoc sub committee on external dosimetry. However, the arguments for making this assumption are summarized below.

Before the introduction of the concept by ICRP (1977), dose limits were applied to the whole body if the irradiation was uniform. If not, they were applied to the blood forming organs or gonads. Measurements with an Alderson phantom showed that for frontal or rotational irradiation, the testes were the most exposed critical organs (Jones 1966). Later measurements made again with the same phantom showed that for a frontal or rotational irradiation, the ratio of effective dose equivalent/exposure was 9 mSv R^{-1} (Jones 1979). Since the difference between this ratio and the previous ratio, critical organ dose/dosimeter exposure was only 3%, no alteration was made. In addition, measurements made by Walsh and Johns (Walsh 1984) confirmed that a ratio of effective dose equivalent/exposure of 8.7 mSv R^{-1} was appropriate when used in the working environment of a nuclear power station. At high photon energies (6 MeV), measurements by Walsh and Facey showed that this ratio fell to 7.6 mSv R^{-1} (Walsh 1986)

E.2 NATIONAL DOSIMETRY SERVICES, BUREAU OF RADIATION AND MEDICAL DEVICES, DEPARTMENT OF NATIONAL HEALTH AND WELFARE

Dosimetry services are available from the Bureau of Radiation and Medical Devices, for monitoring periods of semi-monthly, monthly and quarterly duration. Dosimeters are evaluated at the Bureau in Ottawa and reported to both the subscribing organizations and the National Dose Registry (NDR). The NDR is a central repository of radiation exposure records maintained by the Department of National Health and Welfare.

E.2.1 Description of the Dosimeter

The dosimeters used are quite similar to those designed by the Chalk River Nuclear Laboratories. Each dosimeter uses two TLD elements of the type known as TLD-100. One element, 240 mg cm^{-2} thick, is sandwiched between two 2 mm thick (540 mg cm^{-2}) aluminum filters and is called the whole body element. The skin element is 100 mg cm^{-2} thick and is positioned between thin aluminized mylar filters approximately 7 mg cm^{-2} thick each.

E.2.2 System Calibration

Exposure estimates are derived by comparing the readings obtained from the dosimeter with the readings from exposed calibration dosimeters. These dosimeters are prepared by exposing them to 5 mGy of Cs -137. The exposure is done in a low-scatter environment with the dosimeters in the standard badge holder. The cesium source is calibrated using a secondary standard ionization chamber/electrometer calibrated by the National Research Council of Canada. Readings from unexposed control dosimeters are subtracted from the gross dosimeter readings of the exposed controls to account for their background.

E.2.3 TLD Reader

Currently, we use automatic TLD readers of the Chalk River design. Some modifications have been made to the original instrumentation and it is our intention to eventually convert all readers to a microprocessor controlled configuration. One such reader is currently in use for the assessment of dosimeters used by uranium mine personnel. Calibration dosimeters, both unexposed and exposed, are read as part of each processing batch. Routinely they are used at the beginning and end of the batch as well as being inserted each time the reader alarm signifies an exposure in excess of 800 light units (~ 8.00 mGy). The dosimeters aid in correcting for any

drift in reader sensitivity by allowing us to use a method of linear interpretation between sets of dosimeters and in establishing the dosimeter reading (in light units) to mGy conversion factors for that processing batch.

E.2.4 TLD Thermal Cycle

Prior to assembly, all TLD elements are treated once following the standard annealing protocol of 400°C for 1 hour followed immediately by a 100°C, 2 hour anneal. Once assembled and in use, the routine is as follows: prior to issue 16 hours at 80°C, prior to reading 1 hour at 80°C. No additional heat treatment other than the normal reading cycle is used.

E.2.5 Interpretation of Readings

Dosimeters are read in batches of approximately 180. Each processing tray contains dosimeters that have been used for similar periods of time by similar organizations. Whole body doses are calculated as follows:

(i) All dosimeter readings (in light units) are corrected using individual element correction factors.

(ii) The calibration dosimeters are used to calculate positional dependent correction factors that are then applied to all dosimeters in the batch.

(iii) All dosimeters are reviewed to establish a non-occupational portion of the corrected readings. To aid in the determination of this, there is a simple routine that allows one to calculate the average value of all readings less than or equal to a selected value. This background value is assigned as the batch background and subtracted from all corrected dosimeter readings.

(iv) The following is the algorithm for determination of the whole body dose equivalent ($Dose_p$):

$$Dose_p = \left[(TK - z_{tk}) \cdot CF_{tk} - BKGD_{tk}\right] \cdot \frac{500}{Pi\left[\frac{S_2 - S_1}{n_2 - n_1}\right] + S_1} \cdot K$$

Where TK = gross instrument reading, (1.u.)

z_{tk} = reader background (1.u.)

CF_{tk} = thick element conversion factor (mR/1.u.)

$BKGD_{tk}$ = processing batch "non-occupational" background (mR)

500 = reference exposure level (mR)

p_p = position of dosimeter in processing batch

S_1 = average of leading calibration standards (mR)

S_2 = average of trailing calibration standards (mR)

n_2 = position of "first" trailing standard

n_1 = position of "last" leading standard

K = 0.01 mSv mR^{-1}.

(v) The whole body dose is rounded to the nearest 0.1 mSv for reporting.

(vi) A lower limit of reporting of 0.2 mSv is used.

Skin doses are calculated following exactly the same algorithm as described above, however, the lower limit of reporting is different. To be reported as different from the whole body dose, the skin dose must be at least 1.0 mSv and be greater than the whole body dose by 1.0 mSv as well.

E.3 HYDRO-QUEBEC

E.3.1 Description of the Dosimeter

Hydro-Québec uses the dosimeter designed by Chalk River Nuclear Laboratories. It contains two Harshaw TLD-700 chips. One 240 mg cm^{-2} thick chip is placed between two aluminum filters (540 mg cm^{-2} thick) and is used to evaluate the whole body dose. The other 100 mg cm^{-2} thick chip is placed behind about 7 mg cm^{-2} of aluminized mylar and is used to evaluate the skin dose.

E.3.2 System Calibration

Hydro-Québec's reader is calibrated using the readout of groups of 10 calibration dosimeters irradiated in the badge free-in-air. Calibration dosimeters are irradiated to 1 R by a Cs-137 source traceable to the primary standard of the National Research Council of Canada.

E.3.3 TLD Reader

Hydro-Québec's TLDs are read every two weeks by an automatic TLD reader model HYDI 8502. This is a version of AEP-5256-A designed by Chalk River Nuclear Laboratories and modified by Ontario Hydro.

E.3.4 TLD Thermal Cycle

New TLDs are annealed before the first use at 280°C for 16 hours. After a reading and before reusing the dosimeter, TLDs are maintained at 80°C for 16 hours.

E.3.5 Interpretation of Readings

Hydro-Québec's TLDs are worn at chest level or for special situations, in the area of the body where exposure is expected to be the highest. We evaluate the dose received by soft tissue in the area where the TLD was worn and consider it to be the whole body dose received by the worker. An exposure of 1 R corresponds to a dose of 0.87 rad in air and to a dose in soft tissue of 0.87 x 1.1 = 0.96 rad. So we associate the amount of light emitted by a TLD exposed to 1 R to a whole body dose of 0.96 rem.

TLDs are read in the following sequence:

10 TLDs	exposed to 1 R
5 TLDs	background
150 TLDs	worn by workers
5 TLDs	exposed to 1 R
150 TLDs	worn by workers
5 TLDs	exposed to 1 R
.	.
.	.

150 TLDs	worn by workers
5 TLDs	background
10 TLDs	exposed to 1 R

For a batch of 800 TLD readings, the last series of 10 TLDs of 1 R emits about 10 to 15% less light than the first series of TLDs of 1 R. We correct each readout for this effect as a function of the position of the TLD in the batch, considering that deterioration has taken place at a constant rate. This hypothesis is supported by the readout of 1 R TLDs interspersed within the batch.

E.4 NEW BRUNSWICK ELECTRIC POWER COMMISSION (NBEPC)

Dosimetry in NBEPC has been based upon the Panasonic reader and thermoluminescent dosimeters (TLDs) since 1982.

E.4.1 Description of the Dosimeter

Personnel dosimetry uses two badge types (Table 1). Each contains four elements of thin, granular lithium borate phosphor, shielded by plastic (nearly tissue equivalent) filtration to provide estimates of deep and shallow dose equivalent from photons and beta particles. The average phosphor depth in the shallow element lies at about 24 mg cm^{-2}. Two elements for deep dose assessment lie beneath about 1000 mg cm^{-2} and the remaining element, used for emergency readout if required, or to indicate neutron environments (UD-814AS9), is covered by about 300 mg cm^{-2} of filtration.

TABLE E1

Panasonic TLDs used in NBEPC for Personnel Dosimetry

Badge Type	Phosphor Material
UD-806	Four elements of natural lithium borate.
UD-814AS9	Three elements of lithium-7, boron-11 enriched lithium borate phosphor, and one element of lithium-6, boron-10 enriched lithium borate.

E.4.2 System Calibration

Calibration of the Panasonic TLD reader is performed approximately annually.

All dosimetry readout operations are internally calibrated by means of Run Calibration TLDs. These TLDs are exposed to Cs-137 photons on a Shepherd panoramic irradiator, monitored by an Ionex ionisation chamber traceable to the Canadian National Standard at the National Research Council (NRC), Ottawa.

E.4.3 TLD Reader

The Panasonic reader consists of an automatic changer capable of holding and sequentially presenting 10 trays of 50 TLDs to the reader, without intervention.

The reader and its functions, are monitored at the start of each working day by evaluating the response of a batch of 16 TLDs exposed in contact with a uranium slab for 30 minutes. The daily results must lie within established statistical limits, before the reader is accepted for use in any dosimetry operation.

E.4.4 TLD Thermal Cycle

The phosphor is heated by infrared heating from the controlled pulsing of an incandescent lamp. The lithium borate phosphors require no special annealing cycles or preparation prior to use.

E.4.5 Interpretation of Readings

The raw information from any TLD, is corrected within the TLD reader for drift, and by Rank Correction Factors, set at the factory in Japan for each TLD. Individual Element Correction Factors (ECFs) are applied before backgrounds are subtracted.

A Run Calibration Factor (RCF) for the readout is derived from a comparison of the exposure value provided by the ion chamber relative to the average exposure seen on the ECF-corrected readout of the population of free-in-air calibration TLDs. For personnel dosimetry, the RCF and background TLDs are stored with the personnel TLDs throughout the two week wear term.

An average background value, obtained form the population of control TLDs stored with the personnel TLDs, is calculated and subtracted from the personnel TLD readings. The Lower Limit of Detection for personnel dosimetry at 99% confidence is defined as 4.66 times the standard deviation of the background readings. This value typically lies between 0.1 and 0.2 mSv and is a function of the background variation of the population of control TLDs on readout.

The residual information after background correction, from each personnel TLD, including scatter buildup from the overlying filtration and backscatter from the body, represents absorbed dose in the phosphors of the TLD. By implication from the ICRU model, this absorbed dose from photons also represents the dose equivalent (mSv) at that location and at the relevant depth for the individual. No other corrections are applied to any TLD reading in any of the programs or routines.

E.4.6 Philosophical Basis of the Dosimetry Program

The NBEPC external dosimetry program is based on recommendations of the International Commission on Radiological Protection (ICRP 1977) and the International Commission on Radiological Units and Measurements (ICRU 1976).

E.4.7 Quality Assurance Testing

A Quality Assurance program based upon the results of the Monte-Carlo approach, using the ICRU model, was formulated as the Health Physics Society Proposed Dosimetry Standard which, after extensive testing and some modification, was adopted as ANSI N13.11.

NBEPC has participated each quarter in the Health Physics Society Proposed Dosimetry Standard and in the ANSI N13.11 QA program (ANSI 1983) adopted form it since 1979.

E.5 ONTARIO HYDRO

Personal TLD badges issued to Ontario Hydro workers are collected and read out by Health Physics Services every 2 weeks. Readouts are performed at the Eastern Health Physics Laboratory for the Pickering and Darlington Nuclear Power Stations, Research Division and

non-nuclear OH workers, and at the Western Health Physics Laboratory for the Bruce Nuclear Power Development.

E.5.1 Description of the Dosimeter

The dosimeters are of the Chalk River design. The two TLD elements are both Harshaw TLD-700 material, which is insensitive to neutron exposure. The whole-body element is 240 mg cm^{-2} thick, and is positioned between two aluminum filters in the badge case; each filter is 540 mg cm^{-2} thick. The skin, or shallow, element is 100 mg cm^{-2} thick and is positioned behind about 7 mg cm^{-2} of aluminized mylar.

E.5.2 System Calibration

The doses assigned to OH workers are computed by comparing the readings from their personal dosimeters with the readings from a separate group of calibration dosimeters. These calibration dosimeters are put into standard badges and exposed, in a low-scatter geometry, to 500 mR of Cs-137 gamma radiation. The exposure measurement is traceable to the primary standard maintained by the National Research Council of Canada. In addition, a group of unexposed control dosimeters are used to subtract background dose from the gross dosimeter readings.

E.5.3 TLD Reader

All dosimeters are read using an automatic TLD reader, modified by OH from the original Chalk River design. Sets of calibration dosimeters are inserted at regular intervals during each run. The data from the calibration dosimeters are used: (i) to determine the light-unit-to-mR conversion factors for the personal dosimeters; and (ii) to correct for any drift in reader sensitivity by a process of linear interpolation between calibration sets.

E.5.4 TLD Thermal Cycle

There is no high-temperature (400°C) anneal following readout; at the low doses normally recorded, the reading process itself is sufficient to empty the TL traps. Before the dosimeters are re-issued for use, they are given a low-temperature anneal of 80°C for 16 hours.

E.5.5 Interpretation of Readings

The whole-body dose data from the TLD reader are processed as follows:

(i) dosimeter readings (in light units) are corrected using individual sensitivity factors;

(ii) the net reading of each field dosimeter is determined by subtracting the mean value of the field control dosimeters;

(iii) the net field dosimeter reading [WB(lu)] is converted to mR equivalent [WB(mR)] by applying a calibration factor [CF(mR/lu)] that is obtained using the calibration dosimeters:

$$WB(mR) = WB(lu) \times CF(mR/lu);$$

(iv) the whole-body dose [WB(mrem)] is calculated by applying a conversion factor of 0.87 mrem mR^{-1}:

$$WB(mrem) = WB(mR) \times 0.87(mrem\ mR^{-1});$$

(v) the whole-body dose is then rounded to the nearest multiple of 5 mrem.

The dose-equivalent conversion factor of 0.87 mrem mR^{-1} provides the empirical relationship between the exposure (in mR) at the position of the TLD badge on the chest of the worker, and the dose equivalent (in mrem) to the male gonads. This factor was determined by laboratory experiments at Chalk River, and was subsequently adopted by OH. More recent experiments by OH in nuclear reactor radiation environments have confirmed the validity of using this factor.

The algorithm used to calculate skin dose is similar to the above, except step (iii) becomes:

(iii) The whole-body exposure is subtracted from the skin exposure to get a net value representative of skin beta dose averaged through the thickness of the TL element. This is then multiplied by 2 to convert from the average dose to the dose at a depth of 7 mg cm^{-2} ; and before step (v), the whole-body dose is added to the skin beta dose to get total skin dose from gamma and beta rays.

The net result of steps (iii) and (iv) for skin dose is to multiply the mR equivalent by 2 x 0.87 = 1.74 to obtain beta skin dose. More recent calculations have shown a factor of 1.4 to be more appropriate, but OH has not yet been authorized to make this change to the procedure.